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Repair and maintenance cost analysis of tractors and combines

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Repair and maintenance cost analysis of tractors and combines

by

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LIST OF SYMBOLS

A	annual harvested acres
AC	Allis-Chalmers
h	hour
hrs	hours
H	annual hours of use
INT	International
JD	John Deere
MAF	Massey-Ferguson
N	age of the machine
NI	New Idea
P	Purchase price
R.C.	repair cost
R&M	repair and maintenance
TAH	total accumulated hours of use
TAR	total accumulated repair
WHI	White
Y	repair and maintenance costs ($/year)
$/hr	Dollar per hour

INTRODUCTION

The total annual cost of use of field machines includes charges for ownership and operation. Ownership costs are usually assumed to be independent of amount use and are often called fixed costs or overhead costs. Operating costs vary directly with the amount of use and are referred to as variable costs.

One of the most important costs influencing profit in farming operations is the cost of owning and operating machinery. The distinction between fixed and operating costs is clear for all items except depreciaton and repairs.

Repair costs are a small but significant portion of the total cost of owning and operating farm machinery. Repair costs are generally 10 to 15% of the total annual cost, but because they tend to increase with machine age, repair costs become important in influencing the optimal time of machinery replacement (Rotz, 1985).

The current American Society of Agricultural Engineers (ASAE) recommendations for estimating repair costs are based upon forty years of experience reported by six independent American investigators and compiled by the Machinery Management Committee of ASAE (Table 1).

When tractor powered field machinery first became widely used in the 1920s and '30s much attention was given to costs of owning and operating these machines. Annual repair costs were normally reported as a percentage of the new cost of the machine and no attempt was made to relate this cost to machine age. Repair costs included all costs for maintaining or restoring a machine to working service.

TABLE 1. Rates recommended for estimating repair and maintenance costs for two-wheeled farm tractors[a]

Investigators or reporters	Approx. dates	Geogr. area	Rate % of cost	Comments
Davidson & Henderson	1942	Iowa		Iowa State Univ. Bulletin
Fenton & Barger	1942	Kansas	3.5 % per year	Kansas State Univ. Bulletin
ASAE	1954	USA	35 % per 7500 hr life	First ASAE yearbook w/ cost of use data
Kepner	1962	USA	1.2 % per 100 hrs	
Schaefer-Kehnert	1957	Germany	100 % per 12000 hr life	Highly analytical approach
Hunt	1967	Midwest USA	1 % per 100 hrs	
Bowers	1970	USA	2.2 % per year	
Adelhelm & Steck	1974	Kenya	130 % per 10000 hr life	R & M assumed, not measured
Rahmoo	1975	Pakistan	3 % to 5 % per 100 hr	47 tractors for 1 year
Henderson	1979	Jordan	Varied greatly	96 tractors govt. & private
ASAE	1984	USA	1.2 % per 100 hr	

[a]Beppler and Hummedia, 1985a.

Information available on the use of crop machines in the late 1940s was published as ASAE data in the first edition of the ASAE Yearbook (1954). Total expected repair costs over a machine's life were reported as a percentage of its new cost. The expected useful life of the machine was also given in years-to-obsolescence and total hours of operation. This information was revised in the 1956 edition of the ASAE Yearbook when a few numbers were changed. The revised data remained unchanged for the next six years.

In 1963, the repair cost data were updated through a major revision compiled by R. A. Kepner (ASAE, 1963). Repair cost data were pooled from a much larger data base consisting of 37 sources. The terminology for repair cost was redefined as repair and maintenance cost. This combined cost was again published for a wide variety of machines as a percentage of new cost for both the total cost during wear-out life and the average cost per 100 hours of use. Obsolescence life and wear-out life of each machine were given with some revision from the earlier edition.

In 1966, ASAE data on farm machinery costs and use became the ASAE Standard D230; repair and maintenance cost data again underwent a major revision (ASAE, 1966). In the late 1960s and early '70s, several studies were undertaken to collect repair cost data and to apply mathematical relationships to those data. Bowers and Hunt (1970) surveyed 900 farmers in Illinois and Indiana to obtain repair cost information as a function of machine age and use.

Hunt (1974) collected repair and maintenance cost data for 745 machines over an eight year period on Illinois corn farms. Mathematical models were empirically determined for each type of machine using both a cubic equation and a power equation.

In 1977, Agricultural Machinery Management Data (ASAE D230.2) published in the ASAE Yearbook was again revised. The major change in repair and maintenance cost data was that the power equations determined by Hunt (1974) were presented along with the previous relationships which had evolved over the years.

Tractor numbers increased rapidly during the 1950s, but later, as the number of farm workers decreased, average tractor size increased while tractor numbers declined. A similar trend occurred with combine harvesters, where the capacity of some modern machines is many times greater than that of the biggest combine available only a few years ago. Farm tractors and combines are used on practically every farm, and they represent a major portion of total machinery investiment.

Objectives

The variation in repair costs among machines, the factors that cause this variation, and the magnitude of this variation have not recently been thoroughly investigated. The purpose of this study was to collect and analyse current data related to repair and maintenance costs of tractors and combines. This study was based on data collected from two surveys carried out in central Iowa. The objectives of this study were:

1. To collect current repair cost data for tractors and combines.
2. To compare these data with yearly repair cost estimates derived from ASAE repair cost formulas.
3. To estimate the average tractor life.
4. To estimate the average combine life.
5. To study the factors affecting repair costs of tractors and combines.
6. To develop appropriate new repair cost formulas for tractors and combines.

Definitions

Fixed costs of ownerships, or Fixed costs: The annual costs which do not depend on the amount of machine use. The items are depreciation, interest on investment, taxes, insurance, and housing.

Variable cost or Operating cost: The costs which depend directly on the amount of machine use. These items are labor, fuel, lubrication, and repair and maintenance costs.

Total machinery cost: The sum of fixed and variable costs.

Custom cost: The amount paid for hiring equipment and operator services to perform a certain field operation.

Rent: A rental agreement is a short-term contract that permits use of machinery in exchange for a fee.

Accounting life: The predicted life of a machine based on surveyed use of existing machines and from design life for new machines.

Economic life: The length of time from purchase of a machine to that point where it is more economic to replace it with a second machine that to continue with the first.

Breakdown: An unexpected change in duty status from operational to non-operational, due to mechanical failure.

Failure: The inability of a machine to perform its function under specified field and crop conditions.

Maintenance and service: Periodic activities to prevent premature failure and to maintain good functional performance.

Major overhaul: Extensive rebuilding which extends the useful life of a machine, increases its value or adapts the machine for a different use.

Repair: Restoring a machine to operative condition after breakdown, excessive wear, or accidental damage.

Repair cost: The cost of parts and labor for repairs made in a commercial shop or on the farm.

REVIEW OF LITERATURE

Total Annual Costs

Machinery costs logically fall into two categories, fixed costs and variable costs. Conceptually, variable costs increase proportionally with the amount of operational use of the machine, while fixed costs are independent of use (Hunt, 1983). Some costs do not fit neatly into one or the other classification, and it is not always clear in which category some of the specific costs belong. Interest on the machinery investment, taxes, housing, and insurance depend on calender-year time and are clearly independent of use. The costs of fuel, lubrication, daily service and maintenance, and labor are clearly costs associated with use. The two remaining costs items, depreciation and repair costs seem to be a function of both use and time.

Repair and Maintenance Costs

Repair and maintenance costs of a machine are difficult to estimate because of variabilty among machines and operating conditions from one farm to another, and because good records often are not available. Repair costs are characterized as variable or operating costs, since the amount of wear, and therefore the amount spent for repairs, is proportional to use. There are many factors that can influence repair costs, including:

1. Level of management
2. Level of maintenance

3. Variation of identical machines

4. Local costs for parts and labor

Bowers (1970) suggested some methods which may help a farm manager reduce repair costs as follows:

1. Follow a rigid routine of never taking a machine or tractor to the field until it has a thorough check-up for potential breakdowns.

2. Meet all of the lubrication needs at the proper time and with the recommended lubricant.

3. Never overload a machine.

4. Make minor repairs as needed and before they result in a major breakdown.

5. Follow a super maintenance program to make sure all working parts are functioning properly.

Bowers also indicated that the problem of predicting repair costs becomes even more difficult between geographical regions and over wide ranges of annual use. A real need, but a difficult problem, is to provide guidelines for predicting repair costs that will be meaningful to a conscientious machinery manager.

Culpin (1975) mentioned that repair costs can not accurately be estimated as a percentage of the first cost of the machine (Table 2). He said that there were two main disadvantages in using such figures. One is the fact that annual repair cost should obviously bear some relationship to annual use. The other is that where two machines for doing the same job are compared, there may be a choice between a cheap, badly-constructed machine and an expensive but well-constructed one. In such a case repairs should clearly not be in proportion to capital cost, but rather the reverse.

TABLE 2. Annual repair, maintenance and lubrication cost (not including engine oil) as percent of first cost of American equipment[a]

Equipment	Percent	Equipment	Percent
Moldboard plough	7.4	Mower	4.2
Cultivator	3.8	Side delivery rake	2.5
Disk harrow	3.5	Pickup baler (engine drive)	3.8
Spike-tooth harrow	1.1	PTO combine harvester	4.0
Ridger	5.5	Engine drive combine harvester	3.5
Grain drill	2.2	Self-propelled combine harvester	4.5
Manure spreader	2.0	Forage Harvester	4.5

[a]Culpin (1975).

Bowers (1987) reported that repairs are necessary for a machine to do its job properly. The more agricultural machinery is used, the more repairs are needed to maintain its reliability. Reliability expresses the probability that a machine will perform without unplanned time loss due to a breakdown. There are four main sources of the need for repairs. These are repairs due to:

1. Routine wear

2. Accidental breakage or damage

3. Operator neglect

4. Routine overhauls

Repair costs consist of all expenditures for parts and labor for repairs made in a commercial shop or on the farm. Repair cost records kept by individual farmers vary in their accuracy, form, and completeness (Kepner et al., 1978). Cost surveys must include a large number of farms and machines in order to provide reasonably reliable average values. These average results are not directly applicable to any specific situation, but do provide a basis for general cost estimating.

Liljedahl et al. (1979) stated that the cost of repairs to maintain a tractor during its useful life should include the cost of repair parts, wages of mechanics, and the cost of transportation and time to take the tractor to the parts or to bring the parts to the tractor. Many surveys have been made to determine repair costs for tractors. The results have generally shown exceedingly low repair costs, sometimes even less than 1% of the original cost (list price) of the tractor per year.

In 1965, Huber (1967) conducted a study by personal interviews to determine the effect of type of crop harvested upon the depreciation and repair costs of relatively new self-propelled combines. His study included 125 self-propelled combines. The results showed that soybeans were the cause of more repairs than corn and small grain.

Weber (1966) conducted a study to compare repair costs of diesel and gasoline tractors and to measure the fuel consumption of diesel tractors during a year of operation. Forty-seven new tractors on central Illinios farms were placed under the study in 1956. His results showed that:

1. Repair costs for diesel tractors were higher than those for gasoline tractors.
2. Variation in repair costs of the tractors could not be attributed to make and model.
3. Repair cost per hour was less for tractors with high hours of use per year than for tractors with low hours of use.
4. Repair cost increased with tractor age and use.
5. Engine repair represented only 50% of the total repair costs of diesel and gasoline tractors.

Larson and Bowers (1965) indicated that there was probably less known about repair rates than any other item of machinery cost. They suggested that repairs and maintenance are probably 15% to 20% of the cost of owning a machine for the first half of its life. Most of the reliable data on repairs are for wheel tractors. Available data indicate that the repair rate is fairly low early in the life of the machine and continues to increase as it gets older. Larson and Bowers also said that the repair rate for farm equipment increases faster than the rate for tractors.

In 1966, the American Oil Company, Chicago, Illinois, provided financial support to the Agricultural Engineering Department, University of Illinois, to obtain repair cost data on typical machines in Illinois and Indiana. With this support, Bowers (1970) obtained repair cost data on typical machines in Illinois and Indiana. This survey provided enough reliable data to serve as a basis for estimating repair rates for common farm machines. Equations for estimating repair costs were developed by:

1. Determining the general shape of the repair rate curves.
2. Using the repair rate curves to establish total cost for repairs for the life of the machine.

Bowers's general formula for determining total accumulated repair costs is as follows:

$$TAR = ILP \times RC_1 \times RC_2 \times (L)^{RC_3} \qquad [1]$$

Where:

TAR = Total accumulated repair cost as measured at "L".

L = Percent of life of the machine at the point where accumulated repairs are to be measured. Bowers developed tables of "useful life" for various machine categories.

ILP = Initial list price of machine.

RC_1 is a constant that is the ratio of TAR to ILP as measured at 100% life, and assuming no inflation. RC_2 and RC_3 are repair cost constants that together determine the general shape of the accumulated repair cost curve (Table 3). $RC_2 \times (L)^{RC_3} = 1.0$ at $L = 100$ %.

Hunt and Fujii (1976) used a detailed eight-year survey of repair and maintenance costs for machines on central Illinois farms which permits a study of part failures. Their study showed that the self-propelled combine had the greatest annual cost and the highest incidence of failure among all the machines studied.

TABLE 3. Coefficients for repair cost equation (Accumulated repairs = Initial list price x RC_1 x RC_2 x $(L)^{RC_3}$)[a]

Machine	RC_1[b]	RC_2[b]	RC_3[b]
Wheel tractor	1.2	0.000631	1.6
Crawler tractor	0.8	0.000631	1.6
Combine	0.33	0.000251	1.8
Cotton picker	0.75	0.000251	1.8
Corn picker	0.50	0.000631	1.6

[a]Bowers (1970).
[b]The values shown in this table are based on the assumption that no inflation occurs in the cost for repairs over the life of the machine.

Hunt (1974) obtained data from an eight-year monitoring of the repair and maintenance costs of 745 machines on Illinois corn farms. He did not include the cost of labor for making repairs and performing maintenance in his data. He compared repair and maintenance data obtained from his study with those from previous reports. He found that the previous ASAE values were substantially higher than those obtained in his Illinois study. Only the gasoline tractor, moldboard plow, windrower-conditioner, and stalk chopper values match for the Illinois and ASAE studies. With the exception of the moldboard plow, row cultivator, and forage harvester, the Illinois data (Hunt, 1974) were closer to Illinois and Indiana data (Bowers 1970) than were the ASAE values.

Modifications of Bowers' equations have been made to estimate the accumulated repair and maintenance costs at any point in the life of a machine (Agricultural Engineers Yearbook, 1973):

ASAE Equation	Equation No.	
TAR % = $0.100\ (X)^{1.5}$	1	[2]
TAR % = $0.120\ (X)^{1.5}$	2	[3]
TAR % = $0.096\ (X)^{1.4}$	3	[4]
TAR % = $0.127\ (X)^{1.4}$	4	[5]
TAR % = $0.159\ (X)^{1.4}$	5	[6]
TAR % = $0.191\ (X)^{1.4}$	6	[7]
TAR % = $0.301\ (X)^{1.3}$	7	[8]

where:

TAR % = Total accumulated repair costs to date divided by the list price of the machine, expressed as a percent.

X = 100 times the ratio of the accumulated hours of use to the wear out life (Table 4).

Each of the 7 equations is specific to a given class of machines; Equation 2 for 2-wheel drive tractors, etc.

Fairbanks et al. (1971) conducted a study in 1968 of a total of 114 farm management cooperators representing all areas of Kansas. They developed logarithmic formulas using the least square technique to represent the repair cost functions of field machinery. For tractors they obtained the following equation:

$$Y = (1.4 \times 10^{-3})\ X^{2.19} \qquad [9]$$

TABLE 4. Estimated wear-out life and repair costs for selected machines[a]

Machinery	Estimated wear out life, hr	Total repairs in wear-out life, percent of list price	Use total accumulated repairs, TAR (Equation No.)
Stationary, power unit	12000	120	2
Tractor, 2-wheel drive	12000	120	2
Tractor, 4-wheel drive	12000	100	1
Combine, PTO	2000	100	5
Combine, self-propelled	2000	60	3
Cotton picker, mounted	2000	80	4
Cotton picker, self-propelled	2000	60	3

[a]American Society of Agricultural Engineers Yearbook (1973).

where Y is the accumulated repair cost in percent of initial list price and X is the accumulated operating hours as a percent of the wear-out life in hours. On the other hand, for a 12 to 14 foot self-propelled combine, they obtained the following equation:

$$Y = (5.64 \times 10^{-3})\ X^{1.86} \qquad [10]$$

Farrow et al. (1980) analyzed repair and maintenance cost data for several large grain farms in the Pacific Northwest. They found their data to be similar to the Midwest data collected earlier by Bowers and Hunt (1970) and Hunt (1974). Model parameters were determined for several types of machines using the procedure of Bowers and Hunt.

Rotz (1985) proposed a standard model for repair and maintenance costs of agricultural field machinery as follows:

$$TAR = LIP \times (RC') \times (USE \times S)^{RC_2} \qquad [11]$$

where:

TAR = Total accumulated repair and maintenance cost, \$.

LIP = List price of new machine, \$.

RC_1, RC_2 = Repair cost parameters.

$RC' = RC_1 / (AS)RC_2$

AS = Average or typical field speed, km/h.

USE = Accumulated use, 1000's of hours.

S = Field speed of machine, km/h.

Model parameters were developed for various machines from data available on machine life and repair costs.

Ward et al. (1985b) conducted a study in Ireland of repair costs of 2 and 4 WD tractors. Records of the repair costs, including parts and labor, were available for 42 2-wheel drive (2 WD) and 21 4-wheel drive (4 WD) tractors, over the ten year period 1972 to 1981. They obtained the following equations.

For two-wheel drive

$$TAR = 0.042\ (TAUh)^{1.895} \qquad [12]$$

For four-wheel drive

$$TAR = 0.04055\ (TAUh)^{1.923} \qquad [13]$$

Where:

TAR = Total accumulated repairs, as a percent of the list price of the machine.

TAUh = Total accumulated hours of tractor use as a percent of 12000 h.

According to ASAE (1986b), accumulated repair and maintenance costs at a typical field speed can be determined with the following relationship using the repair and maintenance factors RF_1 and RF_2, and the accumulated use of the machine X.

$$\text{Accumulated repair and maintenance} = P\ (RF_1\ (X)^{RF_2}) \qquad [14]$$

where:

P = Purchase price in current dollars.

RF_1 & RF_2 = Repair and Maintenace factors. See Table 5.

X = Accumulated use of the machine [X = accumulated h/1000].

In time of rapid inflation, the original purchase price must be multiplied by $(1 + i)^n$ where i is the average inflation rate and n is the age of the machine (ASAE Standard, D230.4, 1986a).

Gliem et al. (1986, 1987) conducted a survey to obtain accurate and reliable data regarding agricultural machinery variable costs for grain producers in Ohio's major grain producing counties. Their results showed some startling information related to variable costs and raised some important questions regarding ASAE Machinery Management Data that need further research.

TABLE 5. Repair and Maintenance cost parameters (Accumulated R & M = P (RF_1 $(X)^{RF2}$))[a]

Machine	Estimated life (h)	Repair factors RF_1	RF_2
Tractors:			
2-wheel drive	10000	0.012	2.0
4-wheel drive & crawler	10000	.010	2.0
Combine:			
Pull type	2000	0.18	2.3
Self-propelled	2000	0.12	2.1

[a]ASAE Standard, D230.4, 1986a.

Henderson and Fanash (1984) conducted a survey in Jordan to compare costs of use of government tractors with costs of operating privately-owned ones. A sample of 48 tractors of privately-owned and government-owned tractors were selected randomly. Their results showed that repair costs increased proportionally with age of the tractor. They also found that the larger the area of the farm, the lower the tractor costs per hour.

Beppler and Hummedia (1985a) studied repair costs of agricultural machinery in developing countries. They said that very little data were available concerning the cost of repairing and maintaining tractors in developing countries. The data from Africa and Asia indicate the repair costs may be three to five times greater than corresponding European and American costs.

There are no data available concerning the repair costs of tillage or harvesting machinery in developing countries. They suggested that a research project be designed that will reveal the costs of repair and maintenance of farm machinery in non-industrialized countries.

METHODS

Sample Selection

Hunt and Bowers were the last two American investigators who carried out extensive detailed studies of repair and maintenance costs of farm machines. They obtained most of their repair and maintenaince cost data and developed their equations at the beginning of 1970s. Since that time, some more limited attempts have been made to obtain or modify repair cost data and equations.

The tractor is the principal machine on virtually all farms and is the most expensive single item to purchase on many. Also, combine harvesters are widely owned and are among the most expensive machine to purchase. Since farm tractors and combines are used on practically every farm, and they represent a major portion of total machinery investment, this study is limited to those two machines.

There are various methods of collecting the sample data, including personal interviews, telephone interviews, direct observations, and questionnaires. Each method has its advantages and limitations. A mailed questionnaire sent to a specific group of interested persons can achieve good results, but generally, response rates of this type of data collection are low. The self-administered questionnaire does not require interviewers, and thus its use results in a savings in the survey cost. This savings in cost is usually bought at the expense of lower response rate (Scheaffer et al., 1986).

Two questionnaire surveys were conducted by the author to collect current repair cost data for tractors and combines. The first and the second surveys were mailed in August 1986 and January 1987, respectively. The data were collected from a sample of Iowa farmers who owned these machines in 1984 and 1985. To complete this survey, a questionnaire was developed and mail surveys were conducted. The following procedure was used:

1. In May 1986, I contacted Mr. W. J. Johnson, 109 Curtiss Hall, ISU who provided me with names and addresses of ISU's County Extension Directors.

2. Ten central Iowa counties were chosen randomly for the survey, namely Boone, Greene, Hamilton, Hardin, Jasper, Marshall, Dallas, Franklin, Wright and Carroll. In June 1986, I asked the County Extension Directors from each county to provide me with names and addresses of 50 farmers from their respective counties (The letter which I sent to them is included in Appendix A). Within one week after sending the letters, all the Directors responded by sending me the farmers' names and addresses; some of them sent lists containing 60 to 70 names (A letter which I received from one of them is included in Appendix A).

3. In developing the survey:

   a. I consulted Ms. Toni A. Genalo, Research Associate in the Statistics Dept., ISU who is experienced in conducting surveys.

   b. The total design method (TDM) principle of mail questionnaire construction was used (Dillman, 1978), namely:

      1) the questionnaire is printed as a booklet.

      2) the questionnaire pages are printed in a photographically reduced form.

      3) the questionnaire booklet is reproduced on white paper by a printing method that provides quality very close to the original typed copy.

      4) the front cover of the questionnaire receives the greatest attention and contains (1) a study title, (2) a graphic illustration, and (3) the name and address of the study sponsor.

      5) pretesting to identify construction defects is carried out. In this case some farmers were randomly chosen to test the survey. All of these agreed that the questions were clear and easy to answer.

The farmers were asked to answer questions about the tractors and combines they owned in 1984 and 1985, as follows:

- What is the make, model and year of each machine?
- Do they own this machine?
- What did they pay for the machine?
- Did they purchase the machine new or used?
- What were the meter hours when purchased?
- How many hours currently on the meter?
- How many hours used in 1984?
- How many acres used in 1984?
- How many hours used in 1985?
- How many acres used in 1985?
- What are their estimates of the total life expectancy in hours, for their machines?
- Estimate the total cost of repair and maintenance for all their tractors in 1984 and 1985, separately for each year.
- Estimate the total cost of repair and maintenance for all their combines in 1984 and 1985, separately for each year.
- How many hours of labor did they, their family, or any of their hired help spend on repair and maintenance of machinery in 1984 and 1985?
- Did they include these labor hours as costs when they figured the expense for maintenance and repair?
- What is the total number of acres they operated in 1984 and 1985?
- The survey is reproduced in Appendix A.

After pretests of the survey form indicated that it was well prepared, the survey materials were mailed in the last week of August

1986. It was thought that this was a good time to deliver the surveys, since many farmers had time free from field work during this period. These materials included a personalized letter to each farmer which gave further information concerning the survey. I asked my major professor, Dr. Stephen J. Marley, to sign the letter to strengthen the impression of the survey as an official university project (A copy of the letter is included in Appendix A.). All the farmers were given two telephone numbers they could call if they had any questions concerning the survey. All the County Extension Directors whose counties were included in the survey received a copy of the questionnaire so they would be familiar with the materials in the event that a participating farmer asked them questions. Approximately ten days after the survey materials had been mailed, a follow-up postcard was sent to all non-respondents emphasizing the importance of the study and asking for their cooperation in completing the survey (A copy of the postcard is included in Appendix A.).

Responses were received from 214 farmers, out of 501 surveys mailed (Tables 6 and 7). Sixty-three farmers answered that they have repair costs recorded separately for each machine. A second survey was developed and sent to these farmers to obtain more specific data on individual machines. The second survey form also appears in Appendix A. A response was received from 49 farmers out of 63 surveys mailed (Table 8).

TABLE 6. Machinery cost survey data by county

County name	Deliverable surveys	Useable surveys returned	Negative response	Non-deliver able surveys
Boone	50	17	4	2
Greene	51	19	2	1
Hamilton	50	24	3	3
Hardin	52	16	1	1
Jasper	50	22	4	1
Marshall	49	15	3	-
Dallas	50	20	2	1
Franklin	50	15	5	-
Wright	49	23	-	1
Carrol	50	15	4	1
Total	501	186	28	11

TABLE 7. The first survey response data

Survey disposition	Number	Percent
Nominated farmers	501	
Non-deliverable survey	11	2.2
Total deliverable surveys	490	97.8
Negative response	28	5.7
Useable surveys	186	38.0
Total response	214	43.7

Data Analysis

The farmers were asked to estimate the work done in the course of a year by each individual machine in 1984 and 1985. Work done by a tractor was measured by the hours recorded on the tractor hour meter. Tractor use was measured by the hours accumulated on the hour meter.

TABLE 8. The second survey response data

Survey disposition	Number	Percent
Nominated farmers	63	
Non-deliverable survey	4	6.3
Total deliverable surveys	59	93.7
Negative response	2	3.2
Useable surveys	47	74.6
Total response	49	77.8

Hour meter readings for the 709 individual tractor-years of operation for the first survey and 144 individual tractor-years of operation for the second survey were obtained during 1984 and 1985. Also, the hours used in 1984, the hours used in 1985, the initial purchase price, and the total accumulated use hours were obtained.

The work done by the combines was measured by the hours recorded on the combine hour meter. Hour meter readings for the 193 individual combine-years of operation were obtained during 1984 and 1985. Also, the hours used in 1984, the hours used in 1985, the initial purchase price and the total accumulated use in hours were provided.

These repair cost data for the tractors and the combines from this survey were compared with repair costs estimated for 1984 and 1985 by the following formulas:

- $TAR = ILP \times RC_1 \times RC_2 \times (L)^{RC3}$ [1]

  where each term is as defined on page 12.

- $TAR\ \% = 0.100\ (X)^{1.5}$ [2]

  $TAR\ \% = 0.120\ (X)^{1.5}$ [3]

$TAR\ \% = 0.096\ (X)^{1.4}$ [4]

where each term is as defined on page 14.

- $Y = (1.4 \times 10^{-3})\ X^{2.19}$ [9]

  $Y = (5.64 \times 10^{-3})\ X^{1.86}$ [10]

  where each term is as defined on page 15.

- For two-wheel drive tractors:

  $TAR = 0.042\ (TAUh)^{1.895}$ [12]

  where each term ia as defined on page 17.

- Accumulated repair and maintenance = $P\ (RF_1\ (X)^{RF_2})$ [14]

where each term is as defined on page 17.

These previous formulas were used because they were developed by previous researchers and are included in the literature.

A computer statistics package, SAS, Statistical Analysis System, was used to analyze the data and to estimate repair costs (Appendix B). After estimated repair costs were found from the previous formulas, they were compared with actual current repair costs. The difference between the actual repair costs in 1984 and 1985, and the estimated repair costs from the previous formulas were obtained. t tests were used to determine whether there are real differences between the actual and estimated repair costs or, alternatively, whether the observed difference is small enough to be attributed to chance.

the null hypothesis was $H_O : \mu_D = 0$

the alternative hypothesis was $H_A : \mu_D \neq 0$

The statistical model using t test was:

$$t = (\bar{d} - 0) / S_{\bar{d}} \quad [15]$$

where:

μ_D = the population mean difference between predicted and costs reported in the survey.

$\bar{d}$ = the mean of the difference.

$S_{\bar{d}}$ = the standard deviations of the mean difference.

The survey data were also analyzed by least squares multiple regression. The objective was to develop estimating equations for repair costs per year for tractors and combines.

The following example illustrates the potential usefulness of multiple regression in this study analysis:

Assume one wished to estimate repair costs per year for a wheel tractor or a self-propelled combine. Repair costs will vary with the machine age, the number of hours used per year, the total accumulated hours, the initial list price of the machine, the number of acres operated per year, etc. Other variables that might also affect repair costs are the soil type, the crop type, and the climatic condition.

Some of these variables may be easily quantified; hours of use, machine age, and initial list price are examples. Each of these quantifiable variables may be included in a single estimation equation. Other variables, such as soil type and climatic condition cannot be quantified as easily. Thus, the following hypothetical equation might be developed:

$$Y = a + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 \qquad [16]$$

Where:

Y = repair costs ($/year)

X_1 = initial list price of the machine ($)

X_2 = hours used per year (hrs)

X_3 = age of the machine (years)

X_4 = accumulated hours of use (hrs)

If the parameters are known, Y may be estimated for any given values of X_1, X_2, X_3, and X_4. Further, each b value tells how much Y changes given a one unit change in value of the corresponding X, with other X values remaining constant. One of the objectives of this study is to estimate the values of the various parameters involved.

To estimate the various parameters, there are several methods which one could use. The FORWARD selection method, in which independent variables are entered, one by one into the model, at each stage testing whether there is a significant decrease in the residual sum of squares. For example, suppose we have p independent variables $X_1, X_2, \ldots X_p$. We wish to select the best subset to be used in a linear regression model. Each of the independent variables is used to fit a simple linear regression model of the type

$$Y_i = B_0 + B_1 X_{ji} + e_i. \qquad [17]$$

where:

$i = 1, 2, \ldots, n$ for any $j = 1, 2, \ldots$

and the F-statistic for each is determined. The variable corresponding to the largest F-statistic is chosen to enter the model, if that F-value is significant at some preassigned level. Suppose for simplicity that X_1 is the variable that is chosen to enter the model. Thus after the first step we have the model

$$Y_i = B_0 + B_1 X_{1i} + e_i. \qquad [18]$$

Suppose that we begin with X_2. The 2nd order model will be of the form

$$Y_i = B_0 + B_1 X_{1i} + B_2 X_{2i} + e_i. \qquad [19]$$

A method which is the direct opposite of FORWARD selection is the so called BACKWARD deletion method. In this method, as a first step a regression model with all the variables in the model is computed. Suppose that one variable is removed from the above model and the residual sum of squares determined. From the residual sums of squares of these models, an F-statistic called "F-to-remove" or "F-to-delete" can be computed. We can compute an "F-to-remove" statistic for each variable contained in the original model. From these the lowest F-value can be determined. The variable corresponding to the lowest "F-to-remove" is deleted from the model if the F-value is smaller than the critical value corresponding to a preassigned signficance level.

Another more commonly used procedure in regression model building is the STEPWISE method. This is a combination of both FORWARD selection and BACKWARD elimination. Two preassigned significance levels are selected, one for entry of variables and one for removal. The procedure is similar to FORWARD selection except that after each new variable is entered a single stepdown iteration is performed (Draper and Smith, 1981).

Regressions were run on the NAS AS/9160 (an IBM 3081 compatible computer) using STEPWISE procedure in SAS where each variable was entered in the order that gave the greatest reduction in the variance of the dependent variable. Thus, for example, if 10 independent variables were being considered, 10 separate regression equations were computed. The first equation included one independent variable; subsequent equations included from two to 10 variables as the variable was added that gave the greatest improvement in "goodness of fit". An important property of the STEPWISE procedure is that a variable may be indicated as significant in an early stage and enter the equation, yet, after several other variables are added to the regression equation, the initial variable may become insignificant and automatically be removed.

RESULTS AND DISCUSSIONS

The results are discussed in two parts, corresponding to the objectives of the study. The first part includes analyzing survey data, testing repair cost formulas, and developing new repair cost formulas for tractors. The second part includes analyzing survey data, testing repair cost formulas, and developing repair cost formulas for combines. A more detailed presentation of repair costs is presented in the Appendices A, B, C, D and E. Appendix A presents the letters and the questionnaires of the surveys, while Appendix B presents the SAS computer program for estimating repair costs. Appendices C and D present repair costs for a sample of 50 tractors and combines respectively in 1984 and 1985. In Appendix E, the tables present the statistical analysis of the repair cost data.

Tractors

Characteristics of surveys

The tractor is the principal machine on virtually all farms and is the most expensive single item to purchase on many. All of the tractors in this study were located on central Iowa farms.

The data obtained from the first survey were extracted from an analysis of 709 tractors (Table 9). Of these tractors, 405 had been purchased new and 304 as used machines. The analysis of the data shows that the number of tractors per farm ranged from two to seven. The average was 3.8. John Deere tractors were the most numerous; 40.5 %. Table 10 shows the distribution of the first survey tractors by age.

It indicated that 310 tractors out of 709 were above 14-years-old (47.3 %). However, the survey data include 24 tractors one-year-old (3.4 %) and 14 tractors 2-years-old (2 %). The percentage of the tractors less than 10-years-old was 47 % (Figure 1). The average tractor age was 15-years, with a range from new to 38 years (Table 11).

TABLE 9. Tractor make for the first survey

Tractors	Number	Percent
John Deere	287	40.5
International	243	34.3
Allis-Chalmers	60	8.5
Case	31	4.4
Ford	21	3.0
Massey-Ferguson	16	2.3
White	11	1.6
Others	40	5.6
Total	709	100.0

The annual use in hours for each tractor was obtained. The average annual use in 1984 and 1985 was 356 and 305 hours respectively (Table 11). The average repair cost per tractor in 1984 and 1985 was $631 and $663, respectively.

The repair cost data obtained from the first survey were for all the tractors per farm. For this reason, the second survey was developed to get more detailed repair cost data for each tractor from the farmers who had it available. For the second survey, the data were extracted from an analysis of 144 tractors (Table 12). Of these tractors, 107 had been purchased new and 37 as used tractors. The

TABLE 10. Distribution of the first survey tractors by age

Years of use (tractor age, years)	Number of tractors per group	Percent of total
1	24	3.4
2	14	2.0
3	33	4.7
4	25	3.5
5	55	7.8
6	43	6.1
7	45	6.3
8	27	3.8
9	30	4.2
10	37	5.2
11	18	2.5
12	22	3.1
13	26	3.7
14 and above	310	43.7
total	709	100.0

TABLE 11. Tractor summary data for the first survey

Comparison measures	Mean	Range	Standard deviation
Annual use in 1984 (hrs)	356	0-1000	324
Annual use in 1985 (hrs)	305	0-1500	207
Tractor age (years)	15	New-38	9
Tractor age (meter hrs)	3910	7-17998	2683
Life expectancy (hrs)	8355	600-60000	4461
Repair cost per tractor in 1984 $	631	-	-
Repair cost per tractor in 1985 $	663	-	-

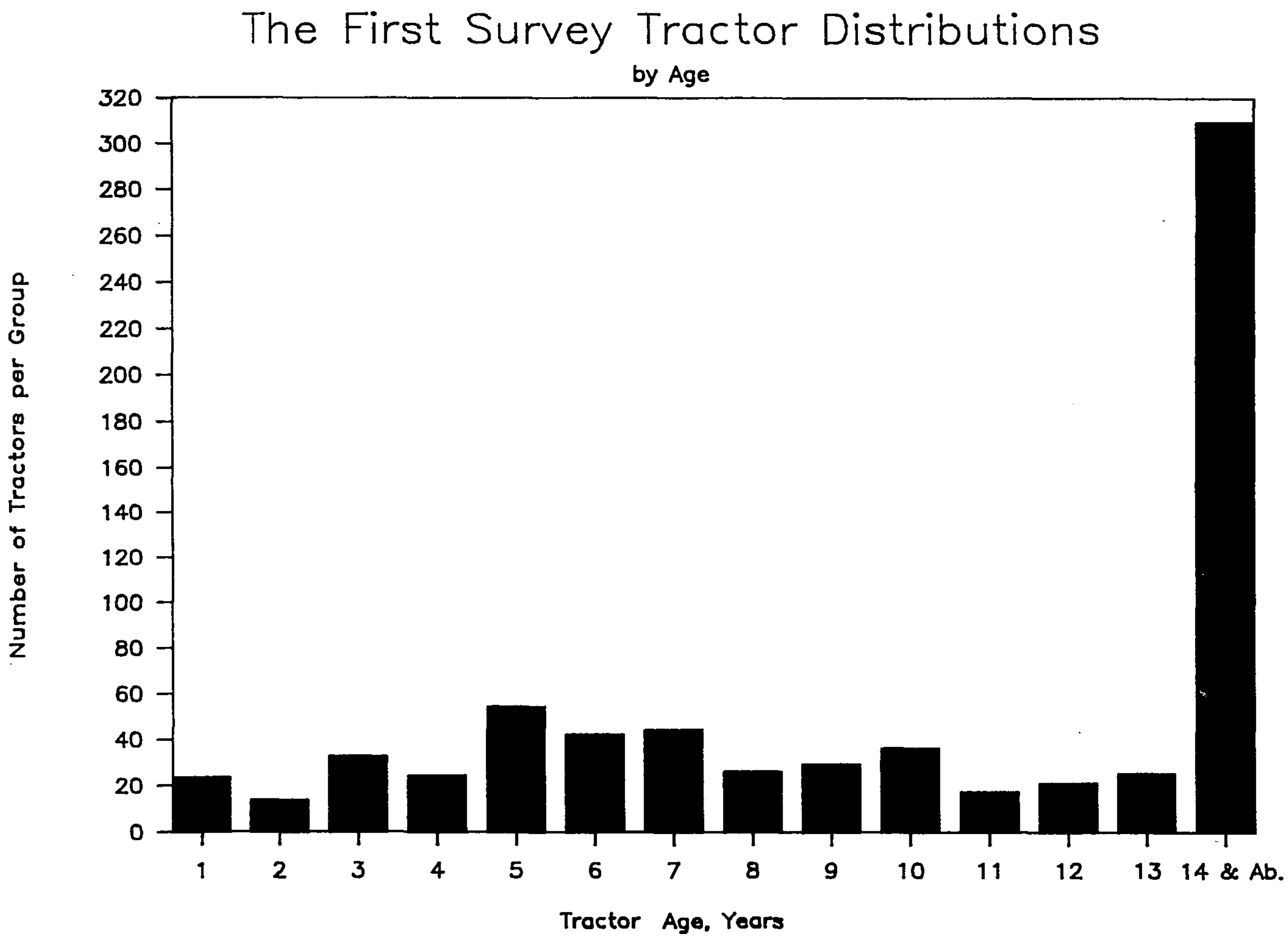

FIGURE 1. The first survey tractor distributions by age

analysis of the data shows that the number of tractors per farm ranged from two to five. The average was 3. International tractors were the most numerous (38.9 %). Table 13 shows the distributions of tractors by age. It indicated that 57 tractors out of 144 were above 14-years-old (39.6 %). However, the survey data included only one new tractor (0.7 %) and 9 tractors 2-years-old (6.3 %). The percentage of tractors less than 10-years-old was 43.9 % (Figure 2). The average tractor age was 12-years; with a range from new to 37-years-old (Table 14). The average annual use in 1984 and 1985 was 322 and 347 hours respectively. Table 14 shows that the average repair cost per tractor in 1984 and 1985 was $685 and $859, respectively.

TABLE 12. Tractor make for the second survey

Tractors	Number	Percent
International	56	38.9
John Deere	47	32.6
Allis-Chalmers	12	8.3
Case	9	6.3
Others	20	13.9
Total	144	100.0

Factors affecting repair costs

The analysis of the data leads to the following points concerning the factors affecting repair and maintenance costs of tractors:

Tractor make and model Repair and maintenance costs per hour in 1984 and 1985 for four various makes of tractors are given in Table 15 and Figure 3. These makes are designated as makes A, B, C, and D.

TABLE 13. Distribution of the second survey tractors by age

Years of use (tractor age, years)	Number of tractors per group	Percent of total
1	1	0.70
2	9	6.3
3	3	2.1
4	6	4.2
5	4	2.8
6	6	4.2
7	11	7.6
8	11	7.6
9	5	3.5
10	7	4.9
11	8	5.6
12	6	4.2
13	10	6.9
14 and above	57	39.6
total	144	100.0

TABLE 14. Tractor summary data for the second survey

Comparison measures	Mean	Range	Standard deviation
Annual use in 1984 (hrs)	322	0-1000	217
Annual use in 1985 (hrs)	347	0-1270	289
Tractor age (years)	12	New-37	8.9
Tractor age (meter hrs)	3834	160-11650	2421
Life expectancy (hrs)	7894	3600-15000	2496
Repair cost per tractor in 1984 $	685	0-6000	950
Repair cost per tractor in 1985 $	859	0-4750	1002

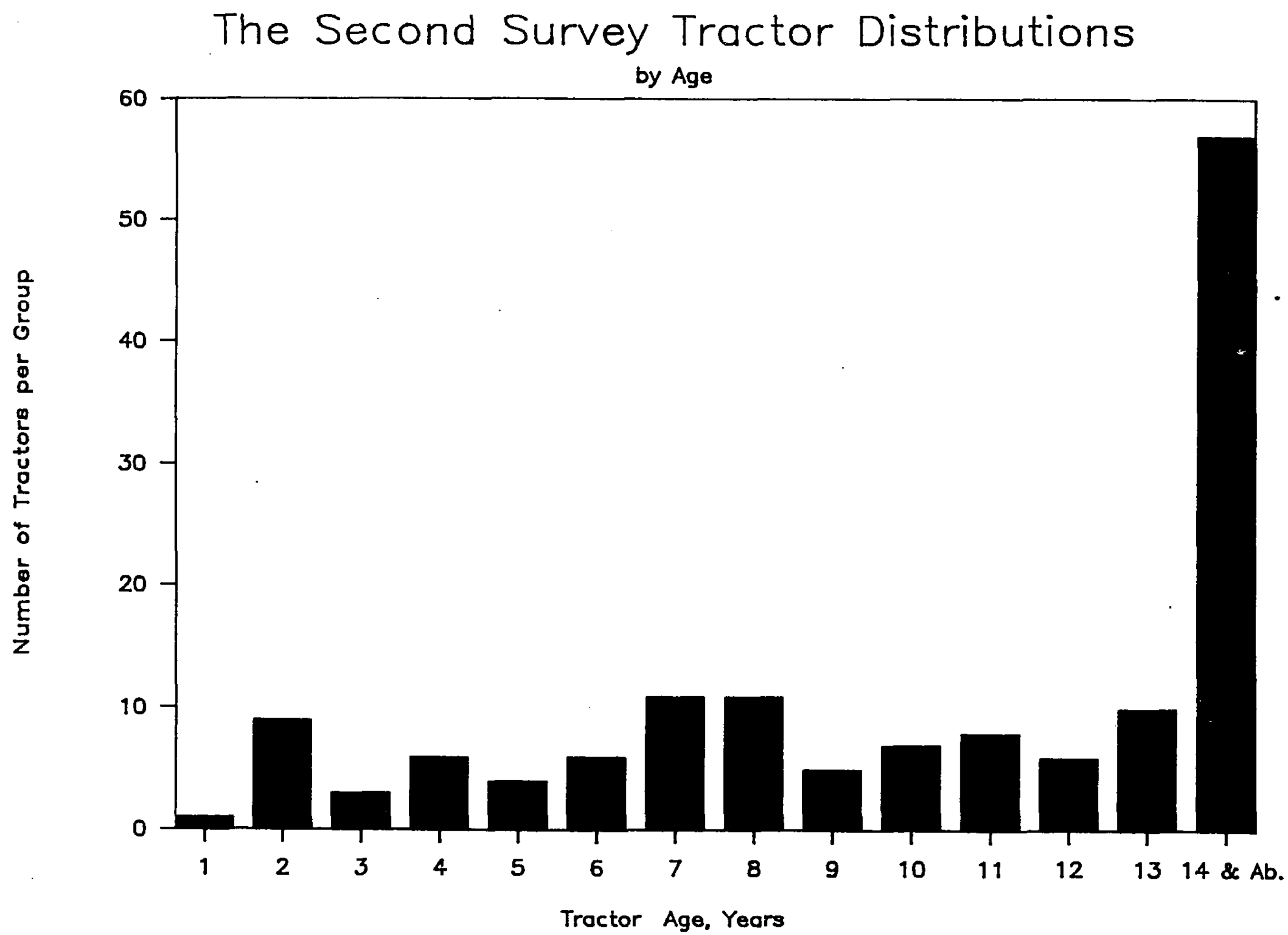

FIGURE 2. The second survey tractor distributions by age

Repair costs for make B were $1.44 /hr and $2.04 /hr in 1984 and 1985 respectively, while repair costs were $2.22 /hr and $1.93 /hr for the make A tractors. It seems from these numbers that repair costs for the make B tractors were lower than for the make A tractors. On the other hand, the annual hours of use for the make B tractors were higher than the make A tractors. This explains why repair costs were lower for make B tractors than the other tracrors. The results showed that there were no effects of tractor makes on repair and maintenance costs.

TABLE 15. Tractor make and repair and maintenance costs in 1984 and 1985

Tractor makes	Average annual use in		Repair and maintenance costs ($/hr)	
	1984	1985	1984	1985
A	266	268	2.22	1.93
B	408	424	1.44	2.04
C	370	356	2.44	2.64
D	345	325	1.86	3.21

<u>Tractor age</u> The repair and maintenance cost per hour in 1984 and 1985 was affected by age of tractors, as is shown in Tables 16 and 17 and Figures 4 and 5, respectively. The analysis of the data showed that repair costs increased with tractor age. Repair and maintenance costs ($/hr) for the second, sixth and tenth year respectively were 0.74, 1.79 and 2.78 in 1984 while they were 1.01, 2.26 and 4.70 in 1985. Repair costs were found to reach a maximum in the range from 8 to 10 years of tractors life and then dropped. The high hourly repair

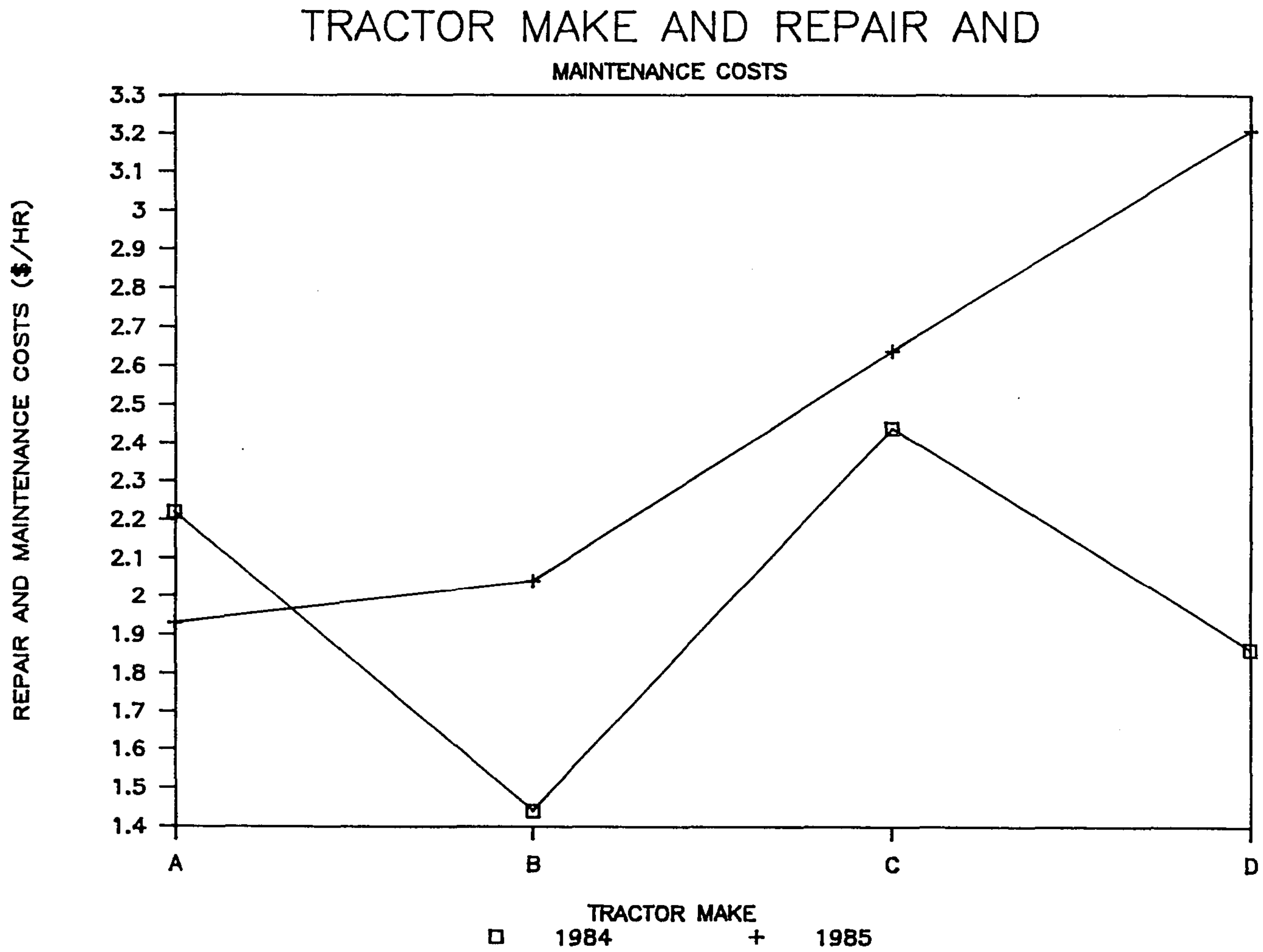

FIGURE 3. Tractor make and repair and maintenance costs

cost during that period could be explained due to engine overhauls, replacement of tires and batteries, fuel injection pump repairs, hydraulic system service, etc. Statistical tests showed the relationship to be highly significant. These results are similar to the findings of Henderson and Fanash (1984).

TABLE 16. Average age of tractors and repair and maintenance costs in 1984

Tractor age after purchase (years)	Number of tractors	Average annual use	Repair and maintenance costs ($/hr)
0-2	12	397	0.74
2.1-4	10	516	0.94
4.1-6	17	390	1.79
6.1-8	16	383	2.15
8.1-10	15	311	2.78
10.1-12	16	348	3.31
Above 12	55	226	2.13

Tractor annual use Table 18 shows repair and maintenance costs ($/hr) for various ranges of annual use. Results indicated that the greatest single factor affecting repair costs of tractors was the annual use. Table 18 and Figure 6 show the relationship between repair costs of tractors and annual hours of use in 1984 and 1985. From the table and the figure, it can be seen that the average repair costs of a tractor of 100 hour annual use was 4.18 $/hr in 1984 and 4.33 $/hr in 1985, respectively. On the other hand, the average repair costs of a

TABLE 17. Average age of tractors and repair and maintenance costs in 1985

Tractor age after purchase (years)	Number of tractors	Average annual use	Repair and maintenance costs ($/hr)
0-2	12	399	1.01
2.1-4	10	577	1.10
4.1-6	17	403	2.26
6.1-8	16	412	2.72
8.1-10	15	290	4.70
10.1-12	16	340	3.52
Above 12	55	265	2.54

tractor of 500 hour and above annual use was 1.60 $/hr in 1984 and 1.46 $/hr in 1985. The data show that the hourly cost of repair and maintenance is inversely related to the amount of annual use and is significantly affected by the annual use. These results are unexpected but are consistent for the two years of the study.

Farm size Table 19 and Figure 7 show repair and maintenance costs ($/hr) for various ranges of farm size. The data do not show any significant effect of farm size on hourly repair and maintenance costs. However, the data show a small positive correlation (but not statistically significant) between increasing farm size and repair costs ($/hr).

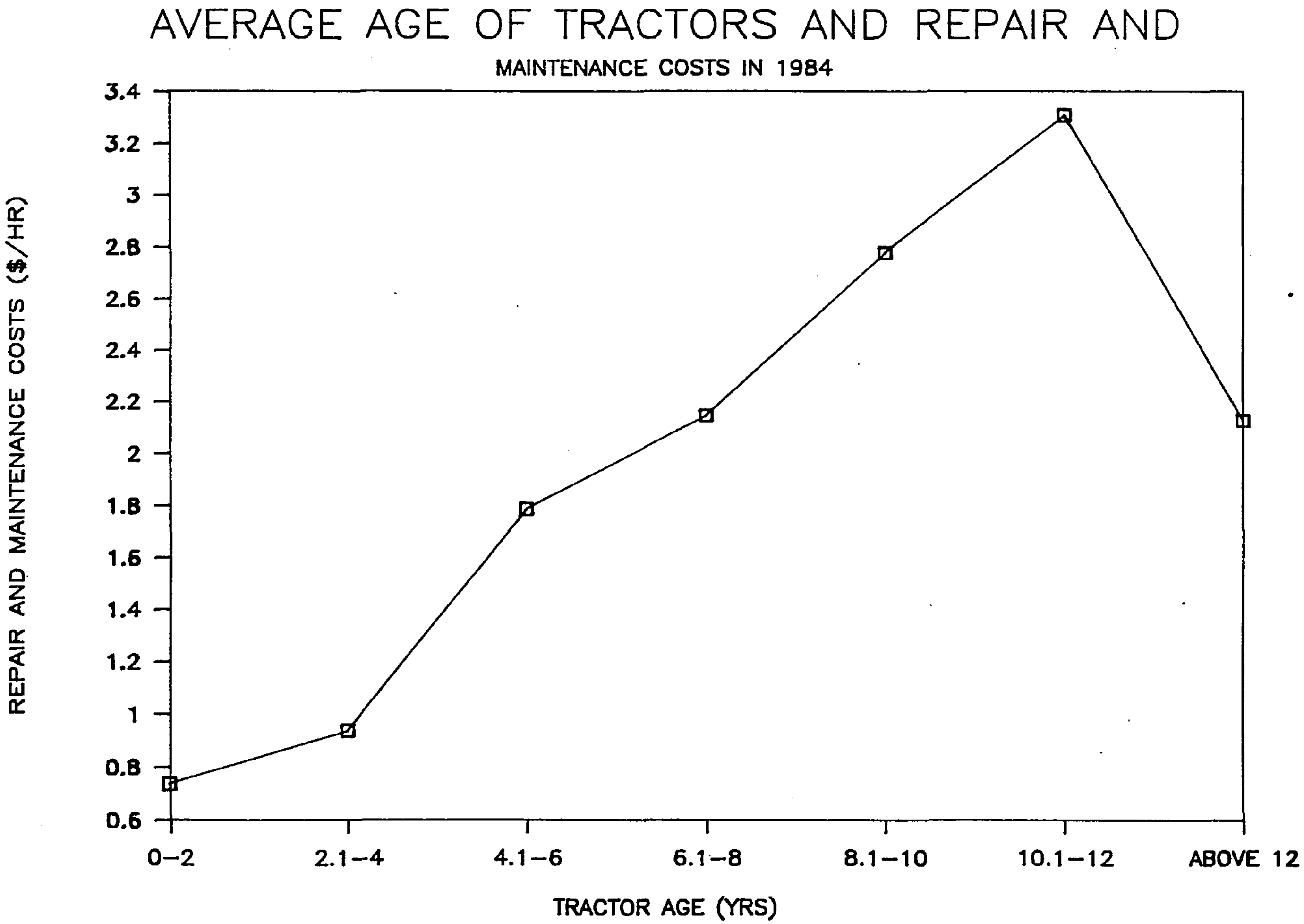

FIGURE 4. Average age of tractors and repair and maintenance costs in 1984

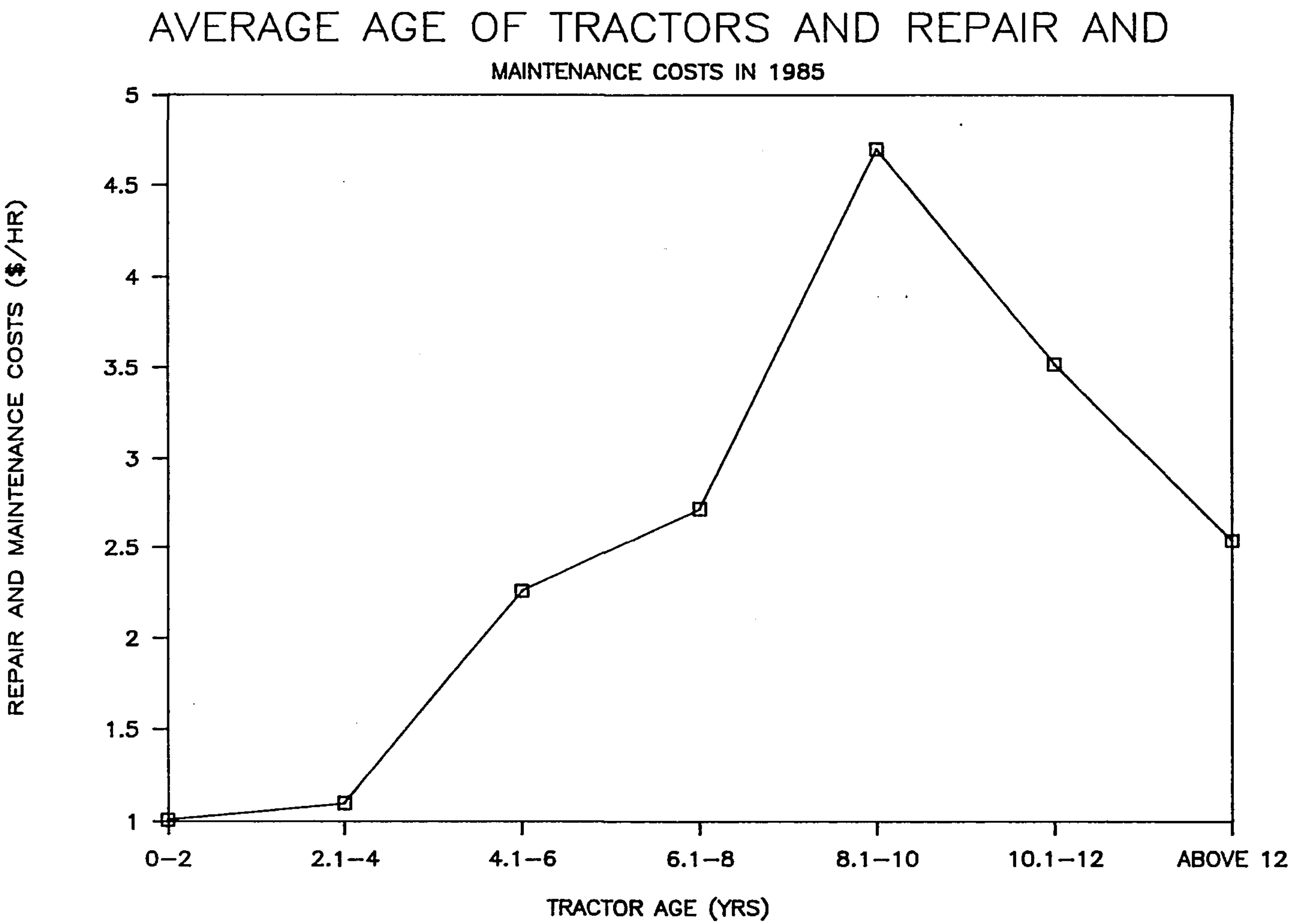

FIGURE 5. Average age of tractors and repair and maintenance costs in 1985

TABLE 18. Average annual use and repair and maintenance costs of tractors in 1984 and 1985

Annual use categories (hrs)	Number of tractors 1984	1985	Average annual use in 1984	1985	Repair and maintenance costs ($/hr) 1984	1985
Up to 100	21	21	65	63	4.18	4.33
101-200	28	29	177	176	2.63	3.76
201-300	32	29	263	259	2.05	3.34
301-400	13	18	381	357	2.21	3.28
401-500	21	16	478	449	2.00	1.48
Above 500	17	21	744	852	1.60	1.46

Testing repair cost formulas

Tractor use was measured by the hours accumulated on the hour meter. For the 107 tractors purchased new, hour meter readings for the 107 individual tractor-years of operation were obtained for 1984 and 1985. Also, the hours used in 1984, the hours used in 1985, the initial purchase price, and the total accumulated use hours were obtained.

These data were adequate for estimating the yearly repair costs for 1984 and 1985. The repair costs for 1984 and 1985 were estimated for the 107 tractors using the five formulas discused in the method section as follows:

Repair cost in 1985 = TAR1986 - TAR1985

Repair cost in 1984 = TAR1985 - TAR1984

Where:

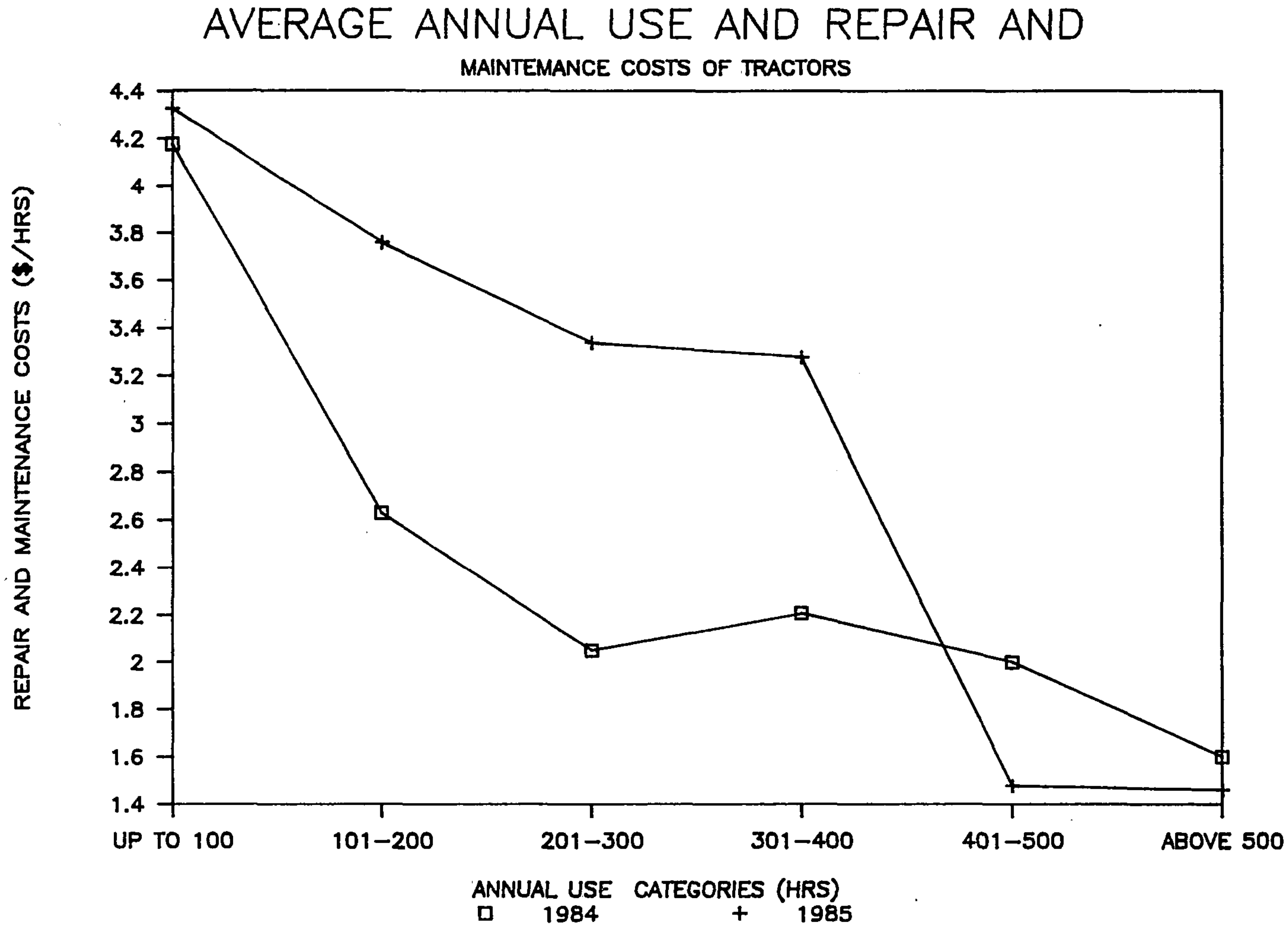

FIGURE 6. Average annual use and repair and maintenance costs of tractors

TABLE 19. Average farm size and repair and maintenance costs of tractors in 1984 and 1985

Farm size category (Acres)	Number of tractors 1984	1985	Average annual use in 1984	1985	Repair and maintenance costs ($/hr) 1984	1985
0-300	24	26	246	260	1.39	1.85
301-500	36	34	290	278	1.48	2.66
501-700	24	18	346	318	2.95	2.86
701-900	17	19	242	340	2.89	2.54
Above 900	17	22	541	476	1.85	2.58

TAR = Total accumulated repair cost of the tractor at the beginning of the year indicated. See Appendix B.

Most of the respondents provided the repair costs of the tractors without including labor cost. However, the labor hours of repair and maintenance were recorded separately. Therefore, farm labor used in making repairs was included in the repair costs at the arbitrary rate of ten dollars per hour.

To test these data in the ASAE formulas, the differences between the actual and the estimated repair costs were obtained for the 107 tractors in 1984 and 1985. Repair costs in 1984 and 1985 for a sample of 50 tractors using the five repair cost formulas (pages 25 and 26) that apply to tractors are presented in Tables C.3 and C.4. A t-test was used to test the null hypothesis that there was no significance between the actual and estimated repair costs. SAS UNIVARIATE

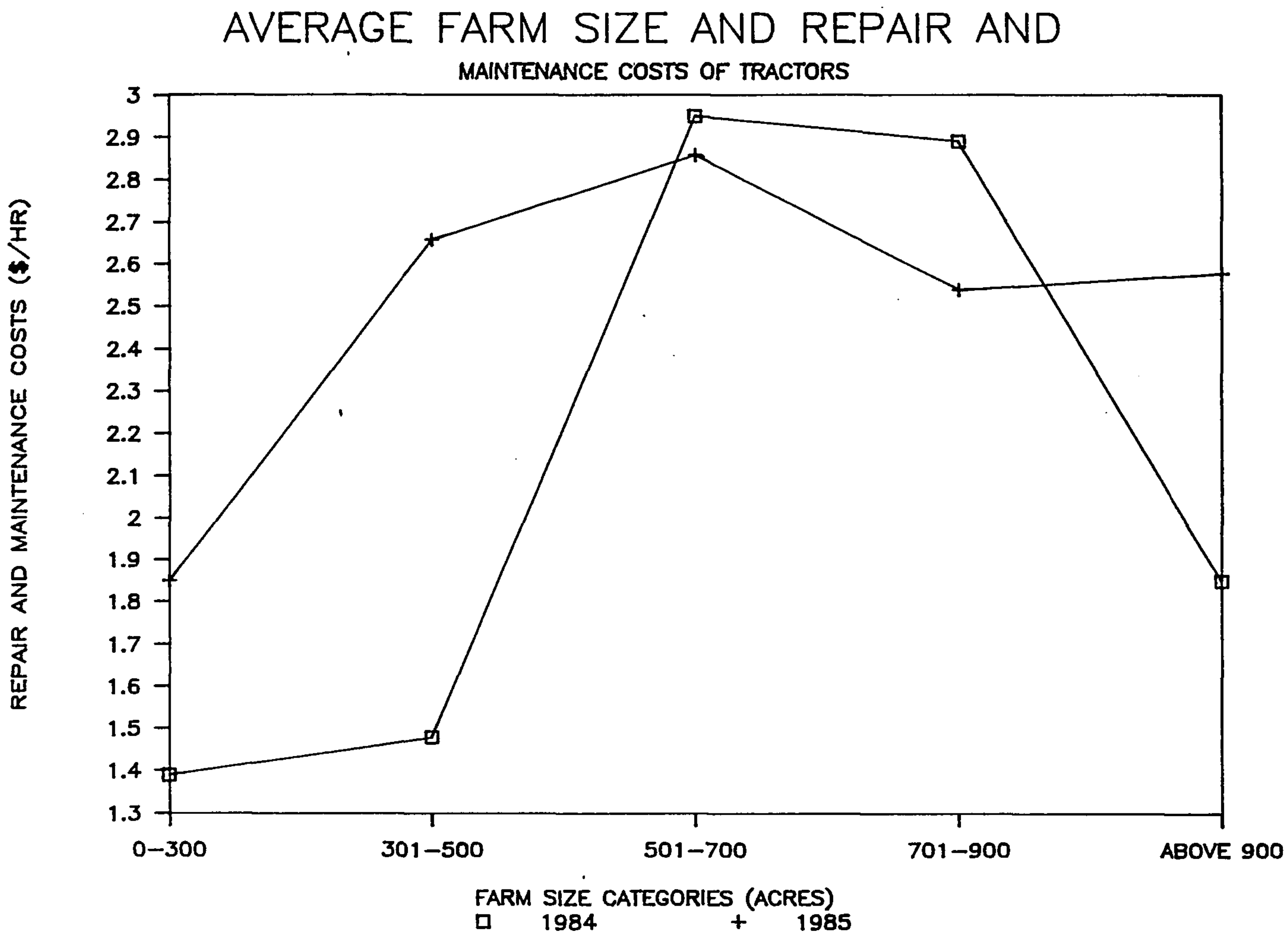

FIGURE 7. Average farm size and repair and maintenance costs of tractors

procedure which produced simple descriptive statistics was used for this purpose (see Appendix E, Tables E.1 to E.5). The statistical analysis indicated that the null hypothesis was rejected for all the equations at significance level 0.0001 except for Ward's equation (TAR = 0.042 $(TAUh)^{1.895}$) for the 1984 and 1985 data. This leads to the conclusion that these formulas do not accurately predict repair and maintenance costs for Central Iowa tractors, except for Ward's equation. Bowers and Hunt (1970) reported that close inspection of individual repair rates indicated wide variations, and to accurately predict repair costs for a single machine on a specific farm appears hopeless.

The comparison of tractor accumulated repair costs predicted by the ASAE equations is shown in Table 20 and Figure 8. It is clear from Table 20 and Figure 8 that equations 1, 2, and 4 give similar estimates of total accumulated repairs. Equation 3 gives the highest value of the accumulated repair costs (258.97 % of the list price) while equation 5 gives the lowest value (33.58 %). The difference between the highest and the lowest value of the accumulated repair costs given by the different equations is larger than 200 % of the new cost. Because data for only two years are available for this central Iowa study, no direct comparison with the total accumulated repair cost equations is possible.

TABLE 20. Comparison of tractor total accumulated repair costs predicted by the ASAE equations

Accumulated use (hrs)	TAR[a]	TAR[b] (% of new cost)	TAR[c] (% of new cost)	TAR[d]	TAR[e] (% of new cost)
1000	2.25	2.64	2.33	1.00	0.15
2000	6.83	6.80	8.68	4.00	0.66
3000	13.06	12.50	18.72	9.00	1.61
4000	20.69	19.25	32.29	16.00	3.02
5000	29.57	26.90	49.29	25.00	4.93
6000	39.59	35.36	69.63	36.00	7.36
7000	50.66	44.55	93.25	49.00	10.32
8000	62.73	54.43	120.10	64.00	13.82
9000	75.74	64.95	150.14	81.00	17.88
10000	89.64	76.07	183.32	100.00	22.53
11000	104.41	87.76	219.60	121.00	27.76
12000	120.01	100.00	258.97	144.00	33.58

[a]Equation 1: $TAR = ILP \times RC_1 \times RC_2 \times (L)^{RC_3}$.

[b]Equation 2: $TAR\ \% = 0.100\ (X)^{1.5}$.

[c]Equation 3: $TAR\ \% = 0.042\ (TAUh)^{1.895}$.

[d]Equation 4: $TAR = P\ (\ RF_1\ \ (X)^{RF_2})$.

[e]Equation 5: $TAR\ \% = (1.4 \times (10)^{-3})\ (X)^{2.19}$.

Modifing and developing new formulas

The analysis of the data shows that the average tractor life estimated by the farmers was 8355 hours (Table 11). Gliem et al. (1986, 1987) found that tractors had an average life expectancy of 9106 hours as estimated by farmers. The tractor average estimated life used in the ASAE formulas was 12000 hours. It is the Ward et al.'s (1985b) opinion that 8000 hours is a more realistic estimate of the actual life of tractors, even though they themselves used 12000 for their equation.

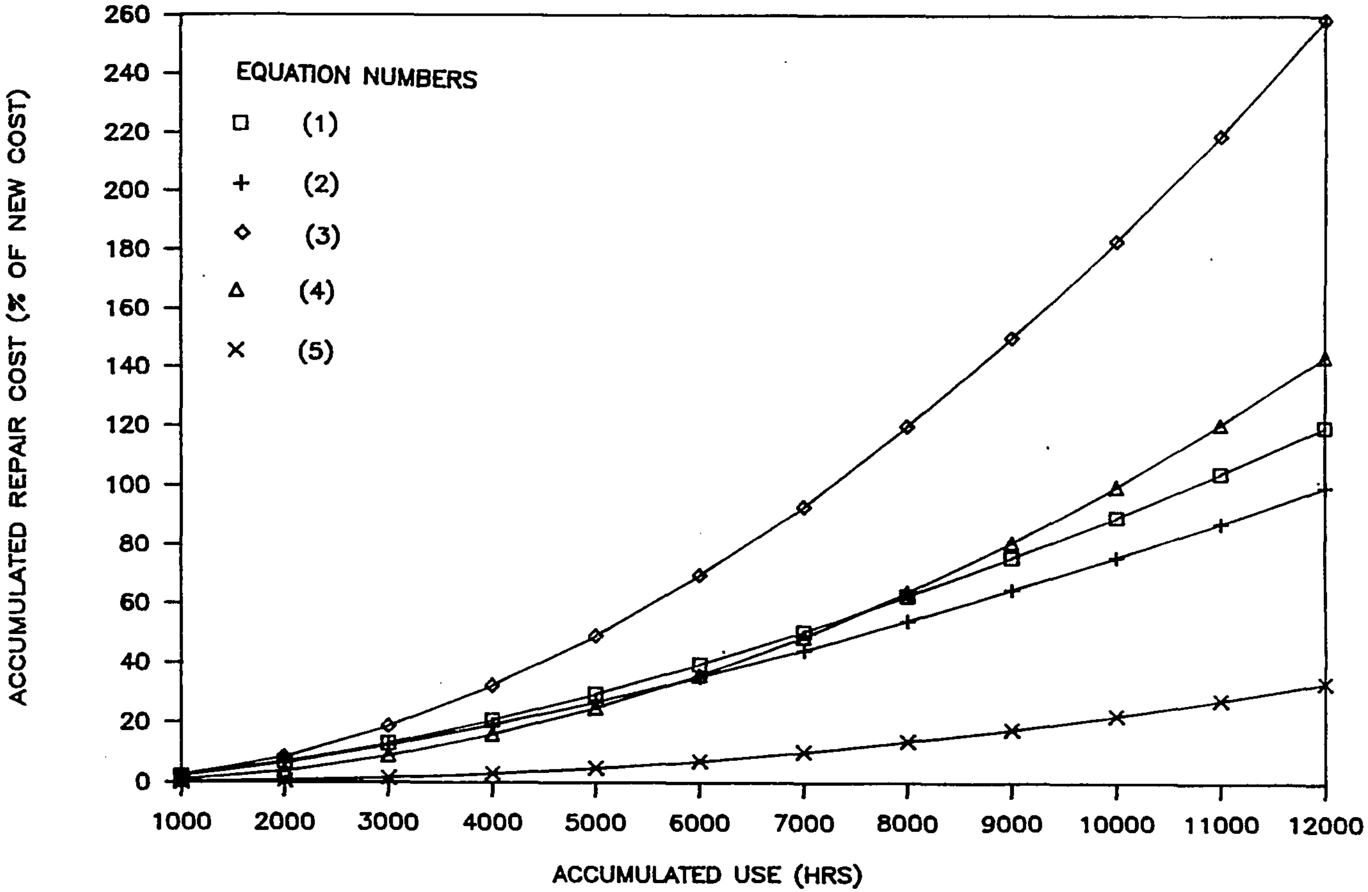

FIGURE 8. Comparison of tractor total accumulated repair costs predicted by ASAE equations

Putting the new estimated life (8355 hours) instead of the current estimated life (12000 hours) makes some improvement in predicting repair costs by the ASAE formulas. So, it is the author's opinion that using 12000 hours as estimated life of tractor is high and not realistic now.

Available data relative to tractor repair costs in 1984 and 1985 included the farmer's estimate of repair costs, the age of the tractor, the annual hours of use, the total accumulated hours of use, the initial list price of the tractor and the annual acres of use. These data were used in three subset selection procedures, FORWARD, BACKWARD and STEPWISE. With FORWARD the significance level for entry of variables (SLE or SLENTRY) used is 0.05 and with BACKWARD, a significance level for deletion (SLS or SLSTAY) of 0.10 is used. The default setting of both SLE and SLS equal 0.15 were used with STEPWISE. The summary of these selection procedures is presented in Appendix E (Table E.6). Using the STEPWISE regression procedure to fit the best model for predicting repair costs per year indicated that tractor age and annual acres of use were not significant. However, the total accumulated hours of use, the initial list price of the tractor and the annual hours of use were the most significant variables in estimating repair costs per year. The following equation is considered as the best fitting model of the data:

$$Y = .072\ TAH + .0096\ P + .66\ H + 78$$

Where:

Y = Repair and maintenance costs ($/year)

TAH = Total accumulated hours of use, at end of year (hrs)

P = Purchase price ($)

H = Annual hours of use (hrs)

To illustrate the use of this new model, it was used to estimate tractor repair costs based on the data collected from the surveys. The previous methods for testing the validity of the ASAE formulas were used exactly the same with the new model. Repair costs in 1984 and 1985 for a sample of 50 tractors using the new repair cost model are presented in Tables C.5 and C.6. The t-test was used to test the null hypothesis that there was no statistically significant difference between the actual and the estimated repair costs (see Appendix E (Table E.7)). Statistical analysis showed that there was no significant difference between the actual and the repair costs estimated by the model. The model fit these data but it has not been tested with any independent repair cost data. Input parameters are the total accumulated hours of use, the annual hours of use and the initial list price of the tractor. Repair costs ($/hr) can also be estimated by dividing the repair costs ($/year) by the annual hours of use.

Combines

Characteristics of surveys

Combine harvesters are widely owned and are among the most expensive machine to purchase. Data for this study were obtained by a survey from the owners of 193 self-propelled combines in Central Iowa. Of these combines, 126 had been purchased new and 67 as used machines.

The analysis of the data showed that the number of combines per farm ranged from one to two. The average was 1.03. John Deere combines were the most numerous 45.1% (Table 21). Table 22 and Figure 9 show the distribution of the combines by age. They indicate that 39 combines out of 193 were 11-years-old or more (20.2%). However, the data include 3 new combines (1.6%) less than one year old and 15 combines (2 years-old) 7.8%. The percentage of the combines equal to or less than 10 years old was 79.8% (Figure 9). The average combine age was 9 years with a range from new to 24 years (Table 23).

TABLE 21. Combine make for the first survey

Combines	Number	Percent
John Deere	87	45.1
International	34	17.6
Massey-Ferguson	30	15.5
Allis-Chalmers	24	12.4
New-Idea	10	5.2
Others	8	4.2
Total	193	100.0

The annual use in hours for each combine was obtained. The average annual hours of use in 1984 and 1985 were 216 hours with a range from 0 to 600 and 217 hours with a range from 8 to 600 hours, respectively. Table 23 shows that the average repair cost per combine in 1984 was $1457 and rose to $1561 in 1985.

TABLE 22. Distribution of the first survey combines by age

Years of use (combine age, years)	Number of combines per group	Percent of total
1	3	1.6
2	15	7.8
3	14	7.3
4	17	8.8
5	22	11.4
6	20	10.4
7	18	9.3
8	12	6.2
9	19	9.8
10	14	7.3
11 and above	39	20.2
total	193	100.0

TABLE 23. Combine summary data for the first survey

Comparison measures	Mean	Range	Standard deviation
Annual use in 1984 (hrs)	216	0-600	115
Annual use in 1985 (hrs)	217	8-600	112
Combine age (years)	9	New-24	4.1
Cumulative usage hours	1442	90-4500	705
Life expectancy (by owner)	3575	1200-15000	1607
Repair cost per combine in 1984 $	1457	0-10000	1661
Repair cost per combine in 1985 $	1561	25-17000	1949

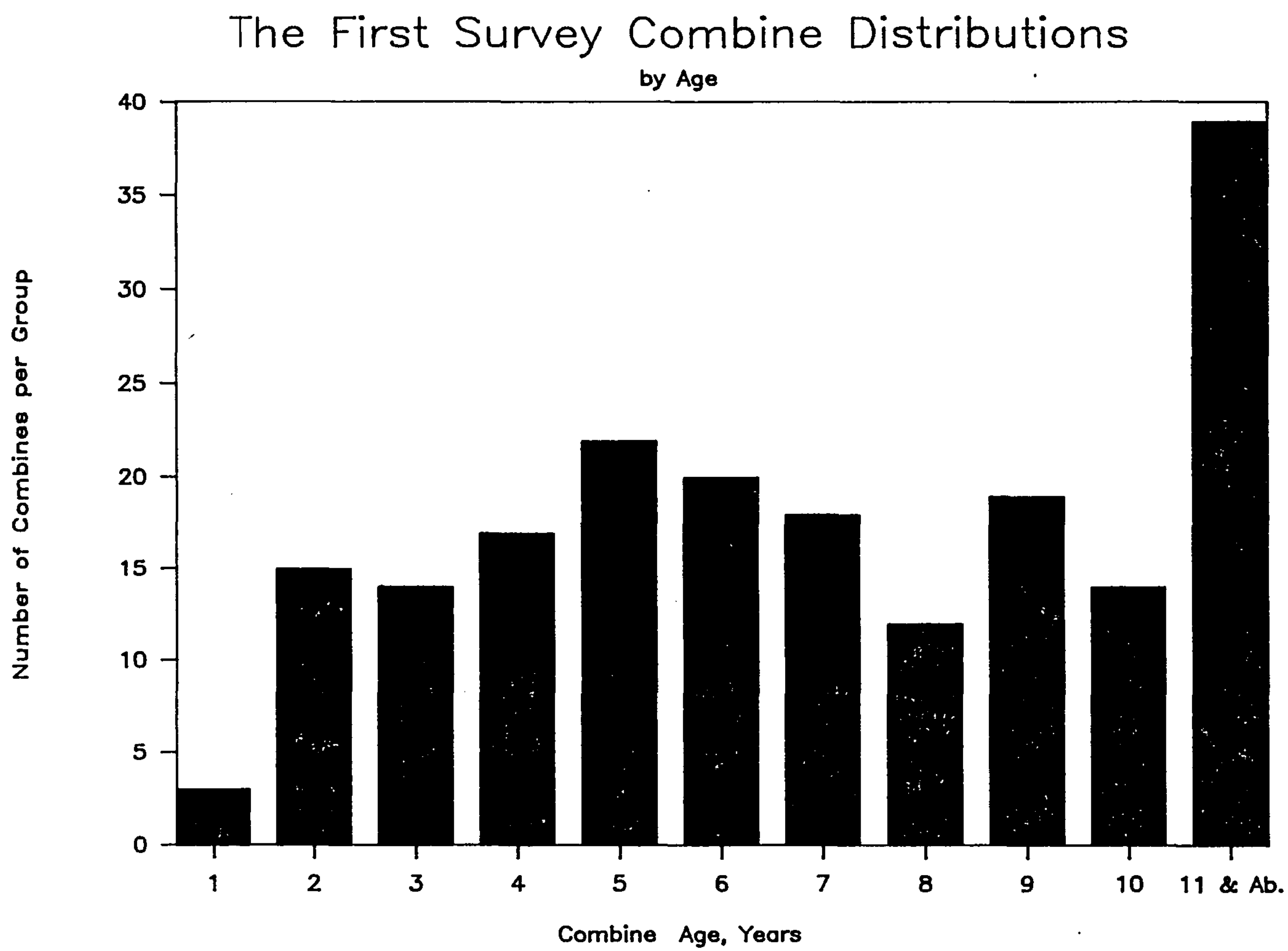

FIGURE 9. The first survey combine distributions by age

Factors affecting repair costs

The analysis of the data leads to the following points concerning the factors affecting repair and maintenance costs of combines:

Combine make and model   Repair and maintenance costs per hour in 1984 and 1985 for four various makes of combines are given in Table 24 and Figure 10. These makes are designated as makes A, B, C, and D. Repair costs for make B were $4.05 /hr and $4.70 /hr in 1984 and 1985 respectively, while repair costs were $9.38 /hr and $9.10 /hr for the make D combines. This seems to indicate that repair costs for make B combines were lower than for other makes. However, make B combines also had the highest average annual use, 268 hours in 1984 and 266 hours in 1985. This helps explain why repair costs were low for make B combines. Statistical analysis showed that there were no effects of combine make on repair and maintenance costs. As Table 23 shows, the standard deviation of the annual repair and maintenance cost was greater than the mean value in both 1984 and 1985.

Combine age   The repair and maintenance cost per hour as affected by age of combines is shown in Tables 25 and 26 and Figures 11 and 12 respectively for 1984 and 1985. The analysis of the data showed that repair costs generally increase with combine age. Repair and maintenance costs ($/hr) for the second, sixth and tenth year respectively were 3.01, 5.63 and 7.93 in 1984 while they were 4.51, 7.78 and 6.66 in 1985. In 1984 repair costs were highest for the 10 to 12 year age group, with a somewhat lower peak for the 6 to 8 year age

TABLE 24. Combine make and repair and maintenance costs in 1984 and 1985

Combine makes	Average annual use in 1984	1985	Repair and maintenance costs ($/hr) 1984	1985
A	215	221	6.69	6.64
B	268	266	4.05	4.70
C	225	228	9.01	8.00
D	156	146	9.38	9.10

group. In 1985, peak repair costs were observed in the 6 to 8 year group. It may be that the high costs for 6 to 8 year old combines reflects the need for engine overhauls at that time, or a thorough replacement of worn parts to ensure additional years of reliable service. Statistical analysis showed that combine age had a significant effect on repair costs.

Combine annual use   Table 27 shows repair and maintenance costs ($/hr) for various ranges of annual use. Results indicated that the greatest single factor affecting repair costs of combines was the annual use. Table 27 and Figure 13 show the relationship between repair costs and annual hours of use in 1984 and 1985. From Table 27 and Figure 13, it can be seen that the average repair cost of a combine of 100 hours annual use was $17.54 /hr in 1984 and $15.12 /hr in 1985, respectively. However, the average repair cost of combine with 300 hours or more annual use was 4.74 $/hr in 1984 and 5.61 $/hr in 1985. The data show that the repair and maintenance costs are closely related

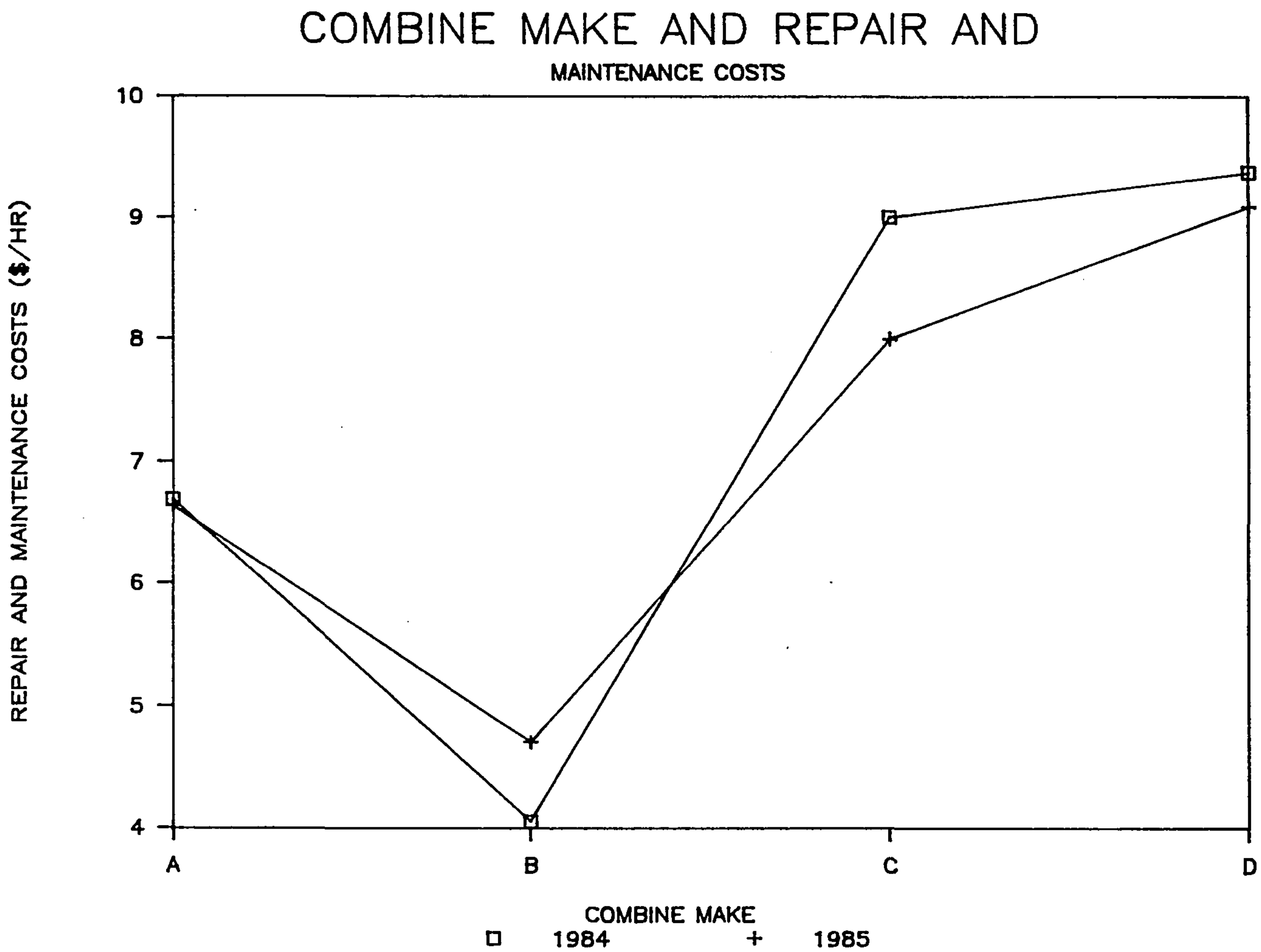

FIGURE 10. Combine make and repair and maintenance costs

TABLE 25. Average age of combines and repair and maintenance costs in 1984

Combine age after purchase (years)	Number of combines	Average annual use	Repair and maintenance costs ($/hr)
0-2	19	290	3.01
2.1-4	31	270	4.24
4.1-6	42	232	5.63
6.1-8	30	204	10.08
8.1-10	33	180	7.93
10.1-12	18	161	12.56
Above 12	20	148	8.55

TABLE 26. Average age of combines and repair and maintenance costs in 1985

Combine age after purchase (years)	Number of combines	Average annual use	Repair and maintenance costs ($/hr)
0-2	19	263	4.51
2.1-4	31	270	5.44
4.1-6	42	233	7.78
6.1-8	30	209	9.77
8.1-10	33	188	6.66
10.1-12	18	174	8.36
Above 12	20	134	9.26

to the amount of annual use and hourly costs decrease significantly for combines as annual use increases. There is no obvious explanation for this unexpected result.

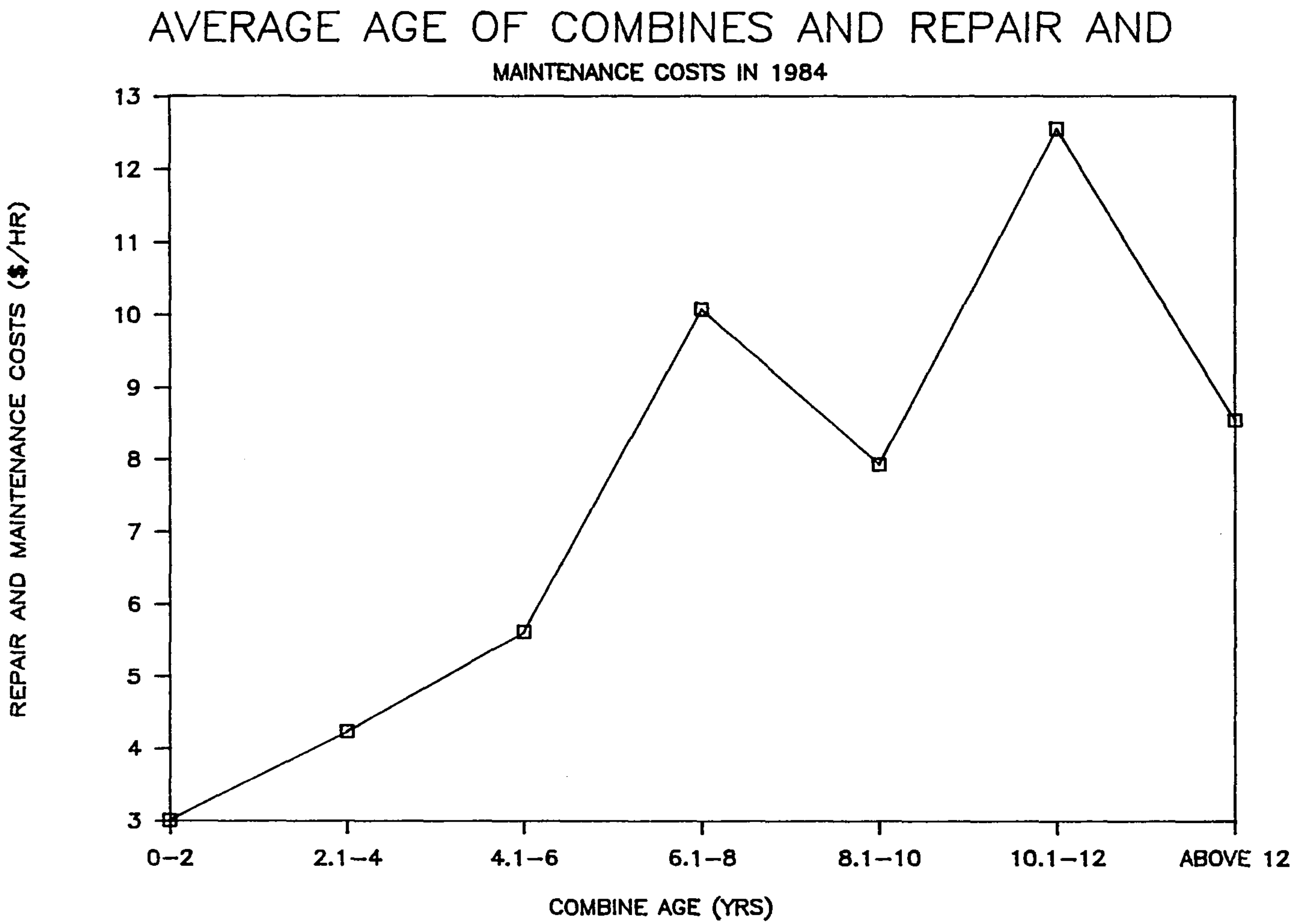

FIGURE 11. Average age of combine and repair and maintenance costs in 1984

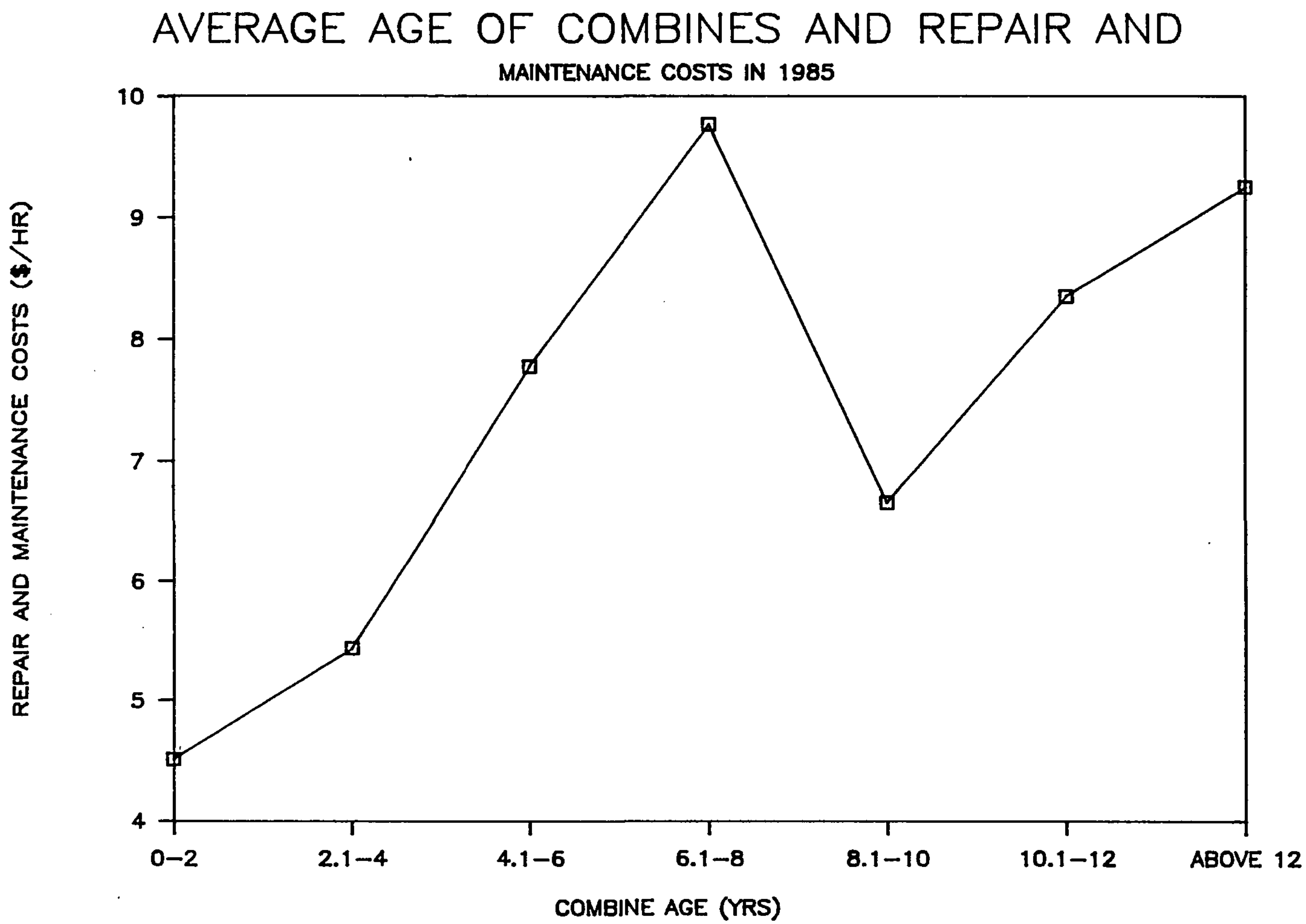

FIGURE 12. Average age of combine and repair and maintenance costs in 1985

TABLE 27. Average annual use and repair and maintenance costs of combines in 1984 and 1985

Annual use categories (hrs)	Number of combines 1984	1985	Average annual use in 1984	1985	Repair and maintenance costs ($/hr) 1984	1985
Up to 100	29	31	64	74	17.54	15.12
101-200	65	60	167	167	7.74	6.71
201-300	54	57	261	257	6.13	6.88
Above 300	25	26	420	418	4.74	5.61

Farm size Table 28 and Figure 14 show repair and maintenance costs of combines for various ranges of farm size. Regarding the effect of farm size on repair and maintenance costs of combines, the data do not show any significant effect of this variable.

Testing repair cost formulas

Combine use was measured by the hours accumulated on the hour meter. Hour meter readings for the 126 combine years in each of 1984 and 1985 were obtained. Hours of use in 1984, hours of use in 1985, the initial purchase price, and the total accumulated use hours were also obtained.

These data were compared with repair costs estimated for 1984 and 1985. The repair costs for 1984 and 1985 were estimated for the 126 combines using the four formulas discussed in the method section as follows:

Repair cost in 1985 = TAR1986 - TAR1985

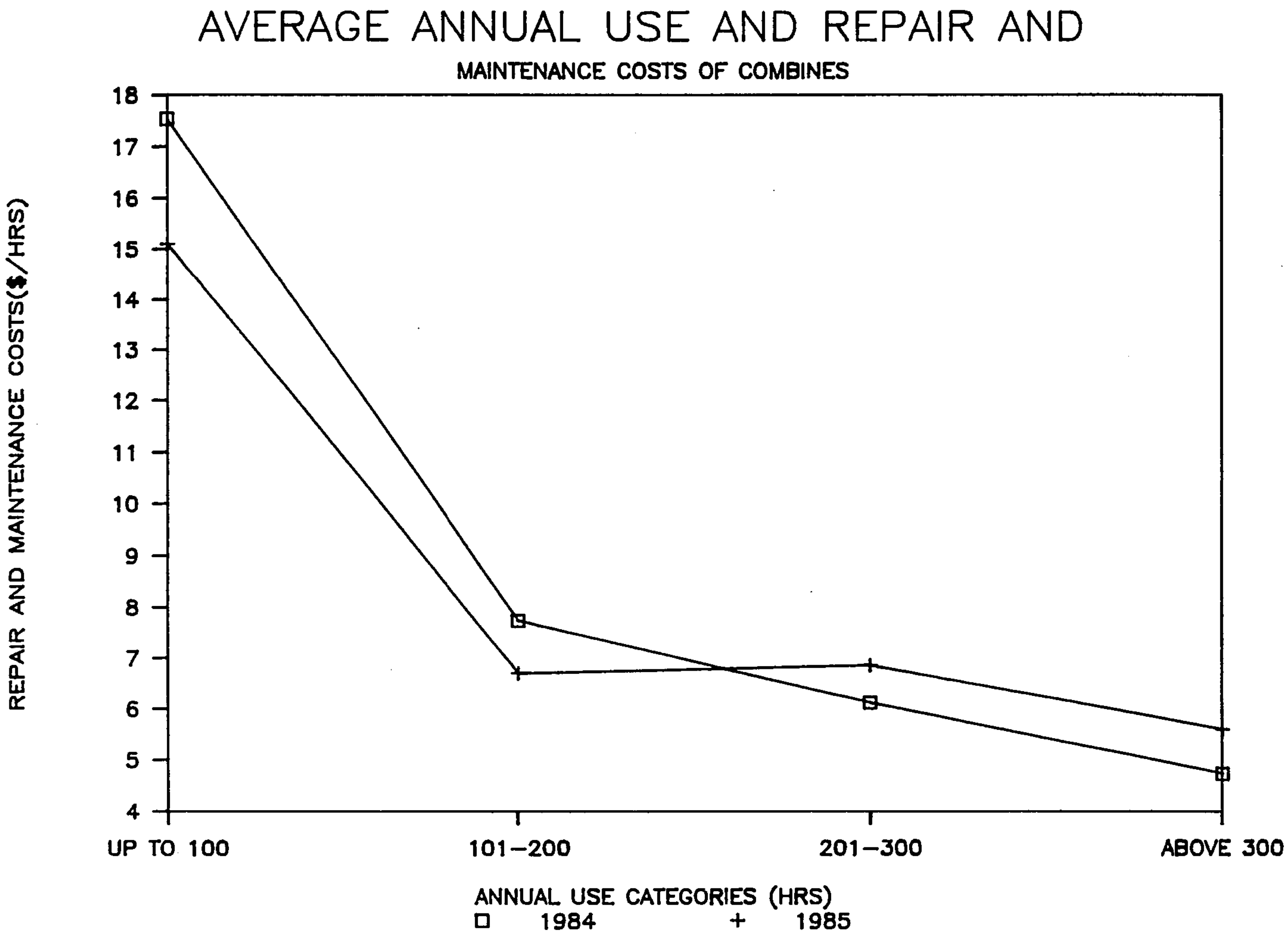

FIGURE 13. Average annual use and repair and maintenance costs of combines

TABLE 28. Average farm size and repair and maintenance costs of combines in 1984 and 1985

Farm size category (Acres)	Number of combines 1984	1985	Average annual use in 1984	1985	Repair and maintenance costs ($/hr) 1984	1985
0-200	23	17	71	87	9.20	8.56
201-400	35	30	179	149	7.81	7.46
401-600	38	37	194	192	5.10	7.02
601-800	34	40	248	228	8.11	7.25
801-1000	21	23	260	282	4.45	4.36
Above 1000	33	36	318	303	6.48	6.55

Repair cost in 1984 = TAR1985 - TAR1984

Where:

TAR = Total accumulated repair cost of the combine at the beginning of the year indicated. See Appendix B.

Most of the respondents provided the repair costs of the combines without including labor cost. However, the labor hours for repair and maintenance were recorded separately. Therefore, farm labor used in making repairs was included in the repair costs at the arbitrary rate of ten dollars per hour.

To test these data in the ASAE formulas, the differences between the estimated and the actual repair costs were obtained for the 126 combines in 1984 and 1985. Repair costs in 1984 and 1985 for a sample of 50 combines using the four repair cost formulas that apply to combines are presented in Tables D.3 and D.4. Student's t-test was

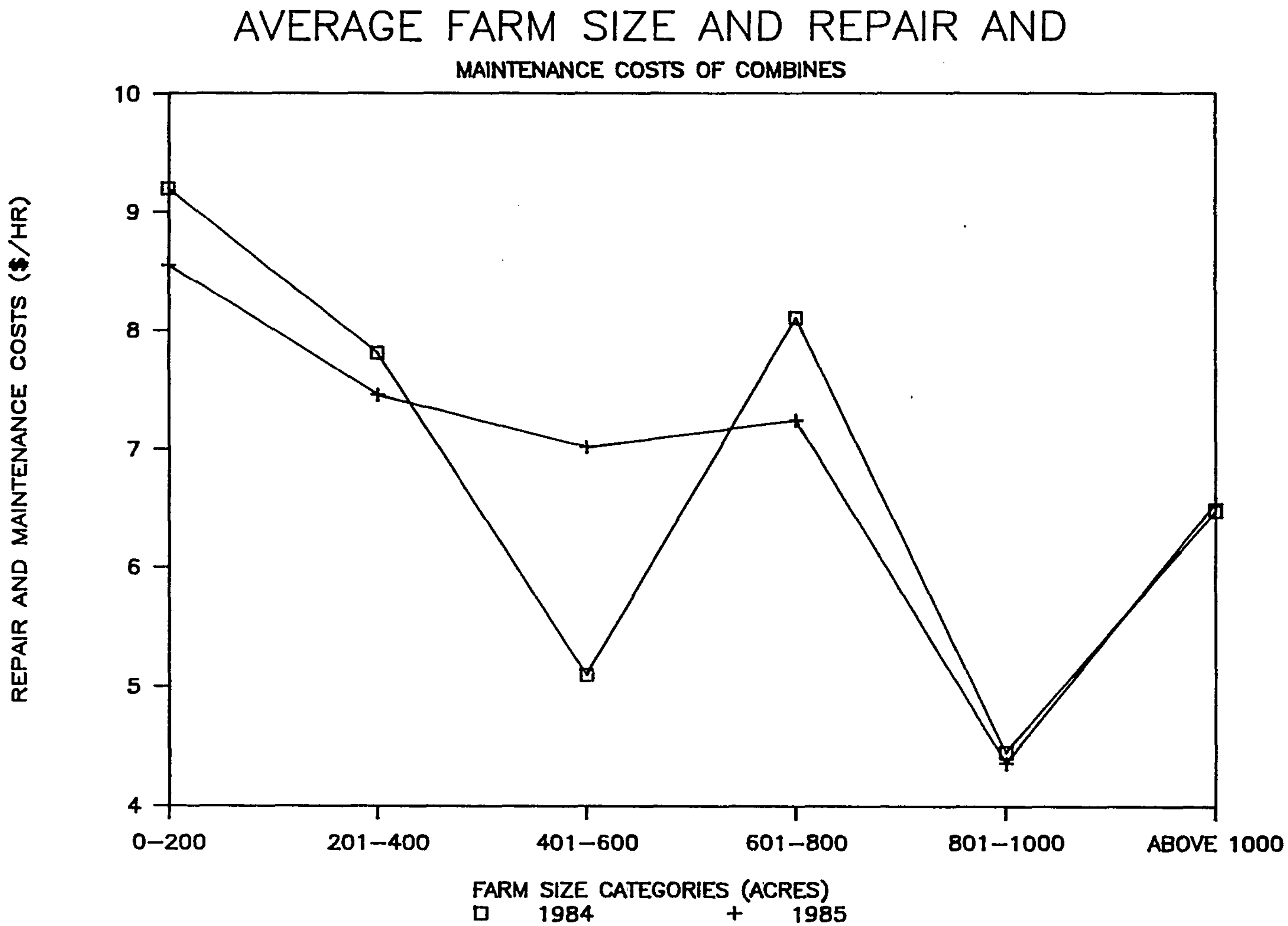

FIGURE 14. Average farm size and repair and maintenance costs of combines

used to test the null hypothesis that the difference between the observed value and the predicted value was zero. The SAS UNIVARIATE procedure which produced simple descriptive statistics was used for this purpose (see Appendix E, Tables E.8 to E 11). Statistical analysis showed that the null hypothesis was rejected for all the equations except one at the significance level 0.0001. However, the Fairbanks equation ($Y = (5.64 \times 10^{-3}) X^{1.86}$) was an exception for 1984 data. This leads to the conclusion that these formulas are not very accurate in predicting yearly repair and maintenance costs for combines used in Central Iowa. Total accumulated repairs could not be predicted.

The comparison of combine accumulated repair costs predicted by the ASAE equations is shown in Table 29 and Figure 15. The equations gave widely different results. It is clear from the data presented in Table 29 and Figure 15 that equation 2 gives the highest value of the accumulated repair costs (60.57 % of the list price) at the end of the estimated life (2000 hrs) while equation 4 gives the lowest value (29.60 %). The highest and the lowest predictions of the accumulated repair costs given by the equations differ by more than a factor of 2.

Modifing and developing new formulas

The analysis of the survey data shows that the average combine life estimated by the farmers was 3575 hours (Table 23). Gliem et al. (1986, 1987) found that combines had an average life expectancy of 3843 hours, 92 % more than the published ASAE estimate. The combine average estimated life used in the ASAE formulas was 2000 hours. Using this

TABLE 29. Comparison of combine total accumulated repair costs predicted by the ASAE equations

Accumulated use (hrs)	TAR[a]	TAR[b] (% of new cost)	TAR[c]	TAR[d] (% of new cost)
200	0.52	2.14	0.41	0.41
400	1.82	6.36	1.75	1.48
600	3.78	11.23	4.10	3.15
800	6.34	16.79	7.51	5.38
1000	9.47	22.95	12.00	8.15
1200	13.15	29.63	17.60	11.45
1400	17.35	36.76	24.32	15.25
1600	22.08	44.32	32.20	19.45
1800	27.28	%52.26	41.23	24.33
2000	32.97	60.57	51.45	29.60

[a]Equation 1: $TAR = ILP \times RC_1 \times RC_2 \times (L)^{RC_3}$.

[b]Equation 2: $TAR\ \% = 0.096\ (X)^{1.4}$.

[c]Equation 3: $TAR = P\ (\ RF_1\ \ (X)^{RF_2})$.

[d]Equation 4: $TAR\ \% = (5.64 \times (10)^{-3})\ (X)^{1.86}$.

new estimated life (3575 hours) instead of the current estimated life (2000 hours) makes some improvement in predicting repair costs by the ASAE formulas. There have been many changes and improvements in combine design and manufacturing during the last two decades. So, it is the author's opinion, and the survey respondents, that using 2000 hours for combine life is low and not realistic now.

Data collected relative to combine repair costs in 1984 and 1985 included the farmer's estimate of repair costs, the annual hours of use, the age of the combine, the total accumulated hours of use, the initial list price of the combine and the annual harvested acres.

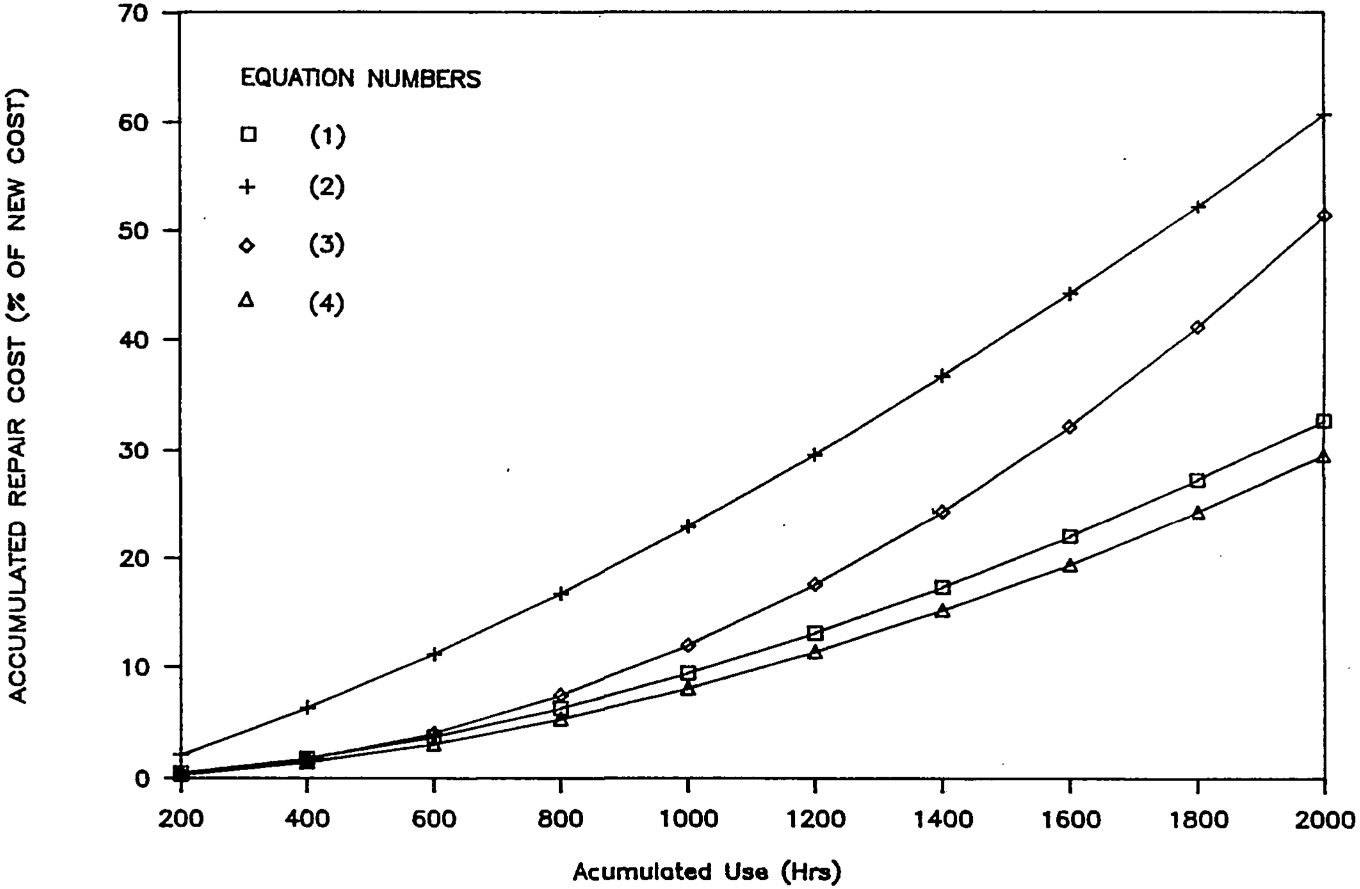

FIGURE 15. Comparison of combine total accumulated repair costs predicted by ASAE equations

These data were used in three subset selection procedures, FORWARD, BACKWARD and STEPWISE, to develop a repair cost model. With FORWARD the significance level for entry of variables (SLE or SLEENTRY) used is 0.05 and with BACKWARD, a significance level for deletion (SLS or SLSTAY) of 0.10 is used. The default setting for both SLE and SLS of 0.15 was used with STEPWISE. The summary of these selection procedures is presented in Table E.12. Using the STEPWISE regression procedure to fit the best model for predicting annual repair costs indicated that the total accumulated hours of use was not significant. Since combine age and annual hours of use are significant, total accumulated hours is a redundant variable. However, the age of the combine, the initial list price, the annual hours of use and the annual harvested acres were the most significant variables in estimating repair costs. The following equation is the model that best fit the data:

$$Y = 241.70\ N + .016\ P + 2.27\ H + 1.07\ A - 1894.9$$

Where:

Y = Repair and maintenance costs ($/year)

N = Age of the combine (yrs)

P = Purchase price ($)

H = Annual hours of use (hrs)

A = Annual harvested acres (acres)

To illustrate the use of this new model for estimating repair costs, it was used to estimate repair costs based on the data collected from the surveys. The previous methods for testing the validity of the ASAE formulas were used in exactly the same way with the new model.

Repair costs in 1984 and 1985 for a sample of 50 combines using the new repair cost model are presented in Tables D.5 and D.6. The t-test was used to test the null hypothesis that there was no statistically significant difference between the estimated costs and costs reported in the survey (see Appendix E, Table E.13). This test showed that there was no significant difference between the actual repair costs and those estimated by the model. The model fit these data but it has not been tested with any independent repair cost data. Input parameters are the age of the combine, the annual hours of use, the annual harvested acres, and the initial list price of the combine. Hourly repair costs for combines ($/hr) can be estimated by dividing annual repair costs ($/year) by the annual hours of use.

SUMMARY AND CONCLUSIONS

One of the most important costs influencing profit in farming operations is the cost of owning and operating machinery. The distinction between fixed and operating costs is clear for all items except depreciaton and repairs. Repair costs are a small but significant portion of the total cost of owning and operating farm machinery.

The variation in repair cost among machines, the factors that cause it, and the magnitude of this variation have not recently been thoroughly investigated. The purpose of this study was to collect and analyse current data related to tractor and combine repair and maintenance costs. Specific objectives of this study were: (a) to collect current repair cost data for tractors and combines; (b) to compare these data with yearly repair cost estimates derived from ASAE repair cost formulas; (c) to estimate expected tractor life; (d) to estimate expected combine life; (e) to study the factors affecting repair costs of tractors and combines; (f) to develop appropriate new repair cost equations for tractors and combines, if needed. Since tractors and combines are used on practically every farm, and they represent a major portion of total machinery investment, this study was limited to them. It was felt that farmers would respond better to a limited survey.

Two questionnaire surveys were conducted by the author to collect current repair cost data for tractors and combines. The data were collected from a sample of Iowa farmers who owned these machines in 1984 and 1985. The total design method (TDM) principle of mail questionnaire construction was used. The farmers were asked to answer questions about the tractors and combines they owned in 1984 and 1985. Responses were received from 214 farmers, out of 501 surveys mailed. Sixty-three farmers answered that they have repair costs recorded separately for each machine. A second survey was developed and sent to these farmers to obtain more specific data on individual machines. A response was received from 49 farmers out of 63 surveys mailed.

The results obtained from the first survey were extracted from an analysis of 709 tractors. The analysis of the data showed that the number of tractors per farm ranged from two to seven. The average tractor age was 15 years; with a range from new to 38 years. The annual use in hours for each tractor was obtained. The average hours of use in 1984 and 1985 was 356 and 305 hours, respectively.

The repair cost data obtained from the first survey were for all the tractors on the farm. The second survey was developed to get more detailed repair cost data for each tractor from the farmers who had it available. For the second survey, the results were extracted from an analysis of 144 tractors. The analysis of the data shows that the number of tractors per farm ranged from two to five. The average was 3. International tractors were the most numerous (38.9 %). The average tractor age was 12 years; with a range from new to 37-years-old. The average repair cost per tractor in 1984 and 1985 was $685 and $859, respectively.

Factors affecting repair and maintenance costs of tractors were studied. These factors included tractor make and model, tractor age, tractor annual use and farm size. The results showed that there were no effects of tractor make on repair and maintenance costs. The analysis of the data showed that repair costs generally increase with tractor age. Repair and maintenance costs ($/hr) for the second, sixth and tenth year respectively were 0.74, 1.79 and 2.78 in 1984 while they were 1.01, 2.26 and 4.70 in 1985. Repair costs were found to reach a maximum in the range from 8 to 10 years of tractors life, and then decreased. The high hourly repair cost during that period might be explained by engine overhauls, replacement of tires and batteries, fuel injection pump repairs, hydraulic system service, etc. Statistical analysis showed the relationship between repair costs and age to be highly significant.

Results indicated that the greatest single factor affecting hourly tractor repair costs was the annual use. The average repair cost of a tractor of 100 hours annual use was $4.18 /hr in 1984 and $4.33 /hr in 1985, respectively. On the other hand, the average repair cost of a tractor of 500 hours and above annual use was $1.60 /hr in 1984 and $1.46 /hr in 1985. The data show that the hourly cost of repair and maintenance is inversely related to the amount of annual use and is significantly affected by it. This result was consistent for both years of the study. The data do not show any significant effect of farm size on hourly repair and maintenance costs.

Tractor use was measured by the hours accumulated on the hour meter. Hour meter readings for the 107 individual tractor-years of operation were obtained in both 1984 and 1985. Also, the initial purchase price and the total accumulated hours of use were obtained for each tractor.

These data were adequate for estimating the annual repair costs for 1984 and 1985. The repair costs for 1984 and 1985 were estimated for the 107 tractors using the following five ASAE formulas:

$$TAR = ILP \times RC_1 \times RC_2 \times (L)^{RC_3}$$

$$TAR\ \% = 0.100\ (X)^{1.5}$$

$$TAR\ \% = 0.042\ (TAUh)^{1.895}$$

$$TAR = P\ (\ RF_1\ \ (X)^{RF_2})$$

$$TAR\ \% = (1.4 \times (10)^{-3})\ (X)^{2.19}$$

To test these data in the ASAE formulas, the differences between the actual and the estimated repair costs were obtained for the 107 tractors in 1984 and 1985. The t-test was used to test the null hypothesis that there was no statistically significant difference between the actual and estimated values. The statistical analysis indicated that the null hypothesis was rejected for all the equations except one at the 0.0001 significance level. Ward's equation (TAR = 0.042 $(TAUh)^{1.895}$) was the only exception for the 1984 and 1985 data. This leads to the conclusion that these formulas, except for Ward's equation, do not accurately predict yearly repair and maintenance costs for Central Iowa tractors.

The data show that the average tractor life estimated by the farmers was 8355 hours. The average estimated tractor life used in the ASAE formulas was 12000 hours. Using the new estimated life (8355 hours) instead of the current estimated life (12000 hours) makes some improvement in predicting repair costs by the ASAE formulas. So, it is the author's opinion that 12000 hours for the estimated life of a tractor is high and is not realistic for current usage. The farmers' estimate of 8355 hours translates to 27.4 years of life at 305 hours of annual use (1985 average use).

Available data relative to tractor repair costs in 1984 and 1985 included the farmer's estimate of repair costs, the age of the tractor, the annual hours of use, the total accumulated hours of use, the initial list price of the tractor and the annual acres of use. These data were used in three subset selection procedures, FORWARD, BACKWARD and STEPWISE. Using the STEPWISE regression procedure to fit the best model for predicting annual repair costs indicated that tractor age and annual acres of use were not significant. However, the total accumulated hours of use, the initial list price of the tractor and the annual hours of use were the most significant variables in estimating repair costs per year. The following equation best fits the data collected in the survey:

$$Y = .072\ TAH + .0096\ P + .66\ H + 78$$

Where:

Y = Repair and maintenance costs ($/year)

TAH = Total accumulated hours of use, at end of year (hrs)

P = Purchase price ($)

H = Annual hours of use (hrs)

This model fits the survey data, but it has not been tested with any independent repair cost data. Input parameters are the total accumulated hours of use, the annual hours of use and the initial list price of the tractor. Hourly repair costs ($/hr) can be estimated by dividing annual repair costs ($/year) by the annual hours of use.

Combine harvesters are widely owned and are among the most expensive machine to purchase. Data for this study were obtained by a survey of the owners of 193 self-propelled combines in Central Iowa. The number of combines per farm ranged from one to two. The average was 1.03. John Deere combines were the most numerous (45.1%). The average combine age was 9 years with a range from new to 24 years. The annual use in hours for each combine was obtained. The average annual hours of use in 1984 and 1985 were 216 hours, with a range from 0 to 600, and 217 hours with a range from 8 to 600 hours, respectively. The average repair cost per combine in 1984 and 1985 was $1457 and $1561, respectively.

Factors affecting repair and maintenance costs of combines were studied. These factors included combine make and model, combine age, combine annual use and farm size. The results showed that there were no effects of combine make on repair and maintenance costs. The analysis of the data showed that repair costs are proportional to combine age. Repair and maintenance costs ($/hr) for the second, sixth and tenth year respectively were 3.01, 5.63 and 7.93 in 1984 while they were 4.51, 7.78 and 6.66 in 1985. Repair costs were found to reach the maximum in the range from 6 to 8 years of combine life, and then generally decrease. The high hourly repair cost during that period might be explained by engine overhauls and replacement or renewal of major components.

Results indicated that the greatest single factor affecting combine repair costs was the annual use. The average repair cost of combine of 300 hour and above annual use was 4.74 $/hr in 1984 and 5.61 $/hr in 1985. The data show that the cost of repair and maintenance is closely related to the amount of annual use and hourly costs decrease with increasing annual use. The data do not show any significant effect of farm size on combine repair and maintenance costs.

Combine use was measured by the hours accumulated on the hour meter. Hour meter readings for the 126 individual combine-years of operation were obtained during 1984 and 1985. Also, the hours used in 1984, the hours used in 1985, the initial purchase price, and the total accumulated use hours were obtained.

These data were compared with repair costs estimated for 1984 and 1985. The repair costs for 1984 and 1985 were estimated for the 126 combines using the following four ASAE formulas:

$$TAR = ILP \times RC_1 \times RC_2 \times (L)^{RC_3}$$

$$TAR\ \% = 0.096\ (X)^{1.4}$$

$$TAR = P\ (\ RF_1\ \ (X)^{RF_2})$$

$$TAR\ \% = (5.64 \times (10)^{-3})\ (X)^{1.86}$$

To test these data in the ASAE formulas, the differences between the actual and the estimated repair costs were obtained for the 126 combines in 1984 and 1985. The t-test was used to test the null hypothesis that there was no statistically significant difference between the actual and estimated costs. Statistical analysis showed that the null hypothesis was rejected for all the equations except one at the 0.0001 significance level. However, the Fairbanks equation ($Y = (5.64 \times 10^{-3})\ X^{1.86}$) was an exception for 1984 data. This leads to the conclusion that these formulas are not accurate in predicting yearly repair and maintenance costs for Central Iowa combines.

The data show that the average combine life estimated by the farmers was 3575 hours. The combine average estimated life used in the ASAE formulas was 2000 hours. Using this new estimated life (3575 hours) instead of the current estimated life (2000 hours) makes some improvement in predicting repair costs by the ASAE formulas. So, it is the author's opinion that using 2000 hours as the estimated life of combines is low and not realistic for current machines and operating practices.

Available data relative to combine repair costs in 1984 and 1985 included the farmer's estimate of repair costs, the annual hours of use, the age of the combine, the total accumulated hours of use, the initial list price of the combine and the annual harvested acres. These data were used in three subset selection procedures, FORWARD, BACKWARD and STEPWISE. Using the STEPWISE regression procedure to fit the best model for predicting repair costs per year indicated that the total accumulated hours of use was not significant. However, the age of the combine, the initial list price, the annual hours of use and the annual harvested acres were the most significant variables in estimating repair costs per year. The following equation is considered as the best fitting model of the data:

$$Y = 241.70\ N + .016\ P + 2.27\ H + 1.07\ A - 1894.9$$

Where:

Y = Repair and maintenance costs (\$/year)

N = Age of the combine (yrs)

P = Purchase price (\$)

H = Annual hours of use (hrs)

A = Annual harvested acres (acres)

Tests of the model have shown that it fits the survey data but it has not been tested against any independent data. Input parameters are the age of the combine, the annual hours of use, the annual harvested acres and the initial list price of the combine. Hourly repair costs for combines (\$/hr) can also be estimated by dividing the annual repair costs (\$/year) by the annual hours of use.

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ACKNOWLEDGMENTS

By the name of God who gave me the will to complete this study, I wish to express my deep gratitude and appreciation to the following persons, who contributed in many ways to my research project and the program of study:

My major professor, Dr. Stephen J. Marley, for his help, encouragement, counseling, and support during every step of this course of study.

Dr. W. F. Buchele, and Dr. T. S. Colvin for their help and guidance during the graduate program.

Dr. D. K. Hotchkiss, and Dr. L. D. Trede for their guidance and serving as members of graduate committee.

I wish to express my thanks and appreciation to Ms. Toni A. Genalo, Research Associate in the Statistics Dept. and to Claudia R. Buttery, former Secretary in the Agricultural Engineering Dept., ISU for their help in designing the surveys.

I would like also to thank the ISU County Extension Directors and the Iowa farmers who participated in the surveys.

I am deeply indepted to my home country, Egypt, and to the Egyptian government for unending help and support. I am also grateful to the U.S.A. Government for granting me a two-year scholarship through the Peace Fellowship program for Egypt.

I would like also to thank my father and my mother who suffered and sacrificed a lot to give their childern what they themselves were not able to have: good schooling and education. I am especially grateful to my brothers and sisters for their continuous love, support, concern and encouragement.

My sincere appreciation is expressed to my wife. Finally, this dissertation is dedicated to my beloved daughter Nor-Elhuda who is the light of my life.

APPENDIX A: LETTERS AND QUESTIONNAIRES

INFORMATION ON THE USE OF HUMAN SUBJECTS IN RESEARCH
IOWA STATE UNIVERSITY
(Please follow the accompanying instructions for completing this form.)

86

1. Title of project (please type): Farm Machinery Repair and Maintenance Cost for Tractors and Combines

2. I agree to provide the proper surveillance of this project to insure that the rights and welfare of the human subjects are properly protected. Additions to or changes in procedures affecting the subjects after the project has been approved will be submitted to the committee for review.

Ismail A. Abdelmotaleb	7/24/86	I. Abdelmotaleb
Typed Named of Principal Investigator	Date	Signature of Principal Investigator

Agr. Engr. Dept., ISU	294-6276
Campus Address	Campus Telephone

3.

Signatures of others (if any)	Date	Relationship to Principal Investigator
	7/24/86	Major Professor
Stephen J. Marley Agr. Engr. Dept., ISU	7/24/86	Stephen J. Marley

4. ATTACH an additional page(s) (A) describing your proposed research and (B) the subjects to be used, (C) indicating any risks or discomforts to the subjects, and (D) covering any topics checked below. CHECK all boxes applicable.

- [ ] Medical clearance necessary before subjects can participate
- [ ] Samples (blood, tissue, etc.) from subjects
- [ ] Administration of substances (foods, drugs, etc.) to subjects
- [ ] Physical exercise or conditioning for subjects
- [ ] Deception of subjects
- [ ] Subjects under 14 years of age and(or) [ ] Subjects 14-17 years of age
- [ ] Subjects in institutions
- [ ] Research must be approved by another institution or agency

RECEIVED
JUL 29 '86
ISU
GRADUATE COLLEGE

5. ATTACH an example of the material to be used to obtain informed consent and CHECK which type will be used.

- [ ] Signed informed consent will be obtained.
- [X] Modified informed consent will be obtained.

6.

	Month	Day	Year
Anticipated date on which subjects will be first contacted:	08	07	1986
Anticipated date for last contact with subjects:	03	30	1987

7. If Applicable: Anticipated date on which audio or visual tapes will be erased and(or) identifiers will be removed from completed survey instruments: 08 07 1987
Month Day Year

8.

Signature of Head or Chairperson	Date	Department or Administrative Unit
H. P. Johnson	7/28/86	Agricultural Engineering

9. Decision of the University Committee on the Use of Human Subjects in Research:

[X] Project Approved [ ] Project not approved [ ] No action required

George G. Karas	7/31/86	George G. Karas
Name of Committee Chairperson	Date	Signature of Committee Chairperson

IOWA STATE UNIVERSITY
of Science and Technology
AMES, IOWA 50011

Department of
Agricultural Engineering
Davidson Hall
Telephone 515-294-2871

June 9, 1986

E. Eugene Neven
County Extension Director
P.O. Box 309
3205 South 6th Street
Marshalltown, IA 50158

Dear Mr. Neven:

I am planning a study of farm machinery repair and maintenance costs. I plan to concentrate on repair and maintenance costs of two major machine types; tractors and combine harvesters. This study is a major part of my Ph.D. program.

To complete this study, I have to develop questionaires and conduct mail surveys. So, I need your help for providing me with fifty names and addresses of farmers from your county. I chose your county for my survey because it is close to Ames. My only requirement is that every farmer own at least a tractor and a combine; otherwise, you can choose any names and addresses.

I promise these names and addresses will be used only for this survey. Finally, I would like to let you know that Mr. W. John Johnson, 109 Curtiss Hall, Iowa State University, advised me to contact you.

Thank you in advance for your help. Please let me know if you need any additional information.

Very truly yours,

I. Abdelmotaleb

Ismail A. AbdelMotaleb
Graduate Student

crb

Iowa State University of Science and Technology

Cooperative Extension Service
MARSHALL COUNTY

3205 South 6th Street
Box 309
Marshalltown, Iowa 50158
515 752-1551

June 12, 1986

Ismail A. AbdelMotaleb, Grad. Student
Department of Agricultural Engineering
Davidson Hall
Iowa State University
Ames, Iowa 50011

Dear Mr. AbdelMotaleb,

Please find enclosed the names, address and zip codes of 50 Marshall County farmers who have tractors and combines. I would appreciate receiving a copy of the letter and survey instrument that will be used in your study. Since many farmers oftentimes, call me asking about these types of surveys, I will be familiar with the material they received.

Thanks!

Sincerely,

Gene Neven

Gene Neven
Marshall County
Extension Director

GN:rw
Enc.

IOWA STATE UNIVERSITY
of Science and Technology
AMES, IOWA 50011

Department of
Agricultural Engineering
Davidson Hall
Telephone 515-294-2871

August 25, 1986

Iowa State University is conducting a study of farm machinery repair and maintenance costs. Repair costs are an important portion of the total cost of owning and operating farm machinery and are highly variable and difficult to predict. For the past 40 years, the American Society of Agricultural Engineers has made recommendations to farmers and other members of the agri-business community based on experience and data collected. In this study we want to collect current data on the costs of repair and maintenance of tractors and combines from a sample of Iowa farmers. This data will be used to examine the previous formulas and test their degree of accuracy under Iowa farm conditions. This study should result in the development of some new formulas which will be more helpful to all interested people.

You have been selected to be a participant in this research study. In order that the results will truly represent Iowa, it is important that each questionnaire be completed and returned. We would greatly appreciate your help in this effort. You are important to our success. Be assured that all information is kept strictly confidential and will be released as statistical summaries only.

The results of this study will be made available to all interested citizens. You may receive a summary of results by checking the box on page 5 and printing your name and address below it. We would appreciate it if you could complete the questionnaire as quickly as possible. When you have completed the questionnaire, tape the edge and mail. Postage is pre-paid.

I would be most happy to answer any questions you might have. Please write or call me or our research coordinator Ismail A. AbdelMotaleb. Ismail's telephone number is (515) 294-6276; mine is (515) 294-4231.

Thank you for your assistance.

Sincerely,

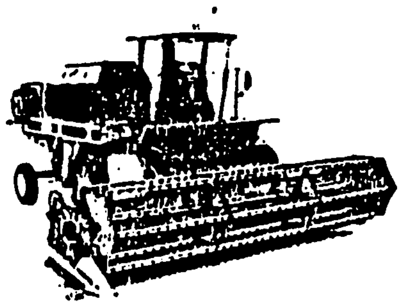
Stephen J. Marley

Stephen J. Marley
Professor

Enclosure: questionnaire
crb

Farm Machinery Repair and Maintenance Cost Study

Tractor and Combine



Iowa State University
Department of Agricultural Engineering

Instructions

Please answer the following questions by circling a response or by entering the name, amount or number asked for. We understand that exact information for some questions would be difficult to get. If you could give us your best estimate we would appreciate it.

If you are unable to give an answer (for example, you do not know the meter hours when purchased), then write "unknown".

Thank you for your help.

In this first section we would like some information about the tractors <u>used on your farm</u> n 1984 and 1985. Please include tractors borrowed as well as those owned. Include all hours he tractor was used.

hat is the ake and model f each?	What is the model year?	Do you own this tractor? (circle)		IF OWNED: What did you pay for the tractor?	Did you purchase new or used? (circle)		Year Purchased	IF USED: What were the meter hrs when purchased?
.	19_____	Yes	No	$_________	New	Used	19_____	_________ Hrs
.	19_____	Yes	No	$_________	New	Used	19_____	_________ Hrs
.	19_____	Yes	No	$_________	New	Used	19_____	_________ Hrs
.	19_____	Yes	No	$_________	New	Used	19_____	_________ Hrs
	19_____	Yes	No	$_________	New	Used	19_____	_________ Hrs
	19_____	Yes	No	$_________	New	Used	19_____	_________ Hrs

2. Complete the following questions about the hours of use of each tractor on Page 1.

TRACTOR MODEL AND YEAR	How many hrs currently on the meter?	How many hrs used in 1984?	How many acres used on in 1984?	How many hrs used in 1985?	How many acres used on in 1985?
1.	_______ Hrs	____ Hrs	_____ Acres	____ Hrs	_____ Acres
2.	_______ Hrs	____ Hrs	_____ Acres	____ Hrs	_____ Acres
3.	_______ Hrs	____ Hrs	_____ Acres	____ Hrs	_____ Acres
4.	_______ Hrs	____ Hrs	_____ Acres	____ Hrs	_____ Acres
5.	_______ Hrs	____ Hrs	_____ Acres	____ Hrs	_____ Acres
6.	_______ Hrs	____ Hrs	_____ Acres	____ Hrs	_____ Acres

3. Based on your experience, what would you say is the total life expectancy, in hours, for the average tractor. (If you aren't sure we would like your best estimate.) ____________________ Hrs

.. Now we'd like some information about the combines used on your farm in 1984 and 1985. Please include combines borrowed as well as owned. Do not include custom combining that you paid someone to do on your farm. (If no combine write NONE on Line 1 and go to Question 6).

What is the make and model of each combine?	What is the model year?	Do you own this combine? (circle)		IF OWNED: Did you purchase new or used? (circle)		IF OWNED: What did you pay for it?	What year did you purchase?	IF USED: What were the meter hrs when purchased?
1.	19____	Yes	No	New	Used	$______	19_____	________ Hrs
2.	19____	Yes	No	New	Used	$______	19_____	________ Hrs

5. For each combine listed above, complete the following questions about the hours of use:

COMBINE MODEL AND YEAR	How many hrs are currently on the meter?	How many hrs used in 1984?	How many acres used on in 1984?	How many hrs used in 1985?	How many acres used on in 1985?
1.	________ Hrs	____ Hrs	_____ Acres	____ Hrs	_____ Acres
2.	________ Hrs	____ Hrs	_____ Acres	____ Hrs	_____ Acres

6. Based on your experience, what would you say is the total life expectancy, in hours, for the average combine. (If you are not sure, we would like your best estimate).
________________ Hrs

7. Please estimate the total cost of <u>repair and maintenance</u> for all your tractors in 1984 and 1985.

   $ ____________________ $ ____________________
   Total cost 1984. Total cost 1985

8. Please estimate the total cost of <u>repair and maintenance</u> for your combines in 1984 and 1985.

   $____________________ $____________________
   Total Cost 1984 Total Cost 1985

9. Do you have repair costs broken down for each machine?

   _____ Yes

   _____ No

10. How many <u>hours of labor</u> did you, your family or any of your hired help put into <u>repair and maintenance of machinery</u> in 1984 and 1985?

    <u>Labor Hours 1984</u> <u>Labor Hours 1985</u>

    Tractors ______________ Hrs Tractors ______________ Hrs

    Combines ______________ Hrs Combines ______________ Hrs

11. Did you include these labor hours as costs when you figured the expense for maintenance and repair in Question 7 and 8?

    _____ Yes What <u>Labor Rate</u> did you use?

    _____ No $________ per hour

12. What is the total number of acres you operated in 1984 and 1985. Please indicate the number by crop type.

	1984	1985
1. Corn	____________	____________
2. Soybeans	____________	____________
3. Other	____________	____________

Thank you very much for your assistance with our project. Iowa State University appreciates your help. Please staple or tape the edge of the questionaire and mail it. If you would like a copy of the results of this study, check the box below.

☐ Yes, I want the results.

Several weeks ago we sent you a questionnaire about farm machinery repair and maintenance costs. We are grateful to those people who completed and returned it. If you have not yet had the opportunity to complete and return it, we are hoping you will do so in the next week or two. It is important to the success of the study that we obtain information from all farmers who were selected to participate.

Iowa State University appreciates your help.

Thank you.

Sincerely,

Stephen J. Marley

Prof. Stephen J. Marley

IOWA STATE UNIVERSITY
of Science and Technology
AMES, IOWA 50011

Department of
Agricultural Engineering
Davidson Hall
Telephone 515-294-2871

January 22, 1987

This past summer, you participated in a farm machinery repair and maintenance cost study which was being conducted by Iowa State University. Data was requested from fifty farmers in each of 10 Iowa counties. 43.7% of the farmers responded. We appreciate your help.

You may be interested to know that the total number of tractors included in the survey was 710. The number of tractors per farm ranged from two to seven, with an average of 3.8. The total number of combines reported was 193, with an average of 1.03.

The formulas presently used for estimating repair costs are out-dated and data collected in this study indicate that we can improve these formulas if we have some additional information. Therefore, we are asking for a little more help from you.

You indicated that you have separate repair costs available for each tractor and combine. Enclosed is a one page questionnaire that we are asking you to complete. We have listed the machinery you owned in 1984 and 1985 as you reported. Please provide us with the repair costs on each individual machine. Your additional help will make the results of this study more accurate and useful.

Would you complete the form as quickly as possible and return it in the postage paid envelope.

I would be most happy to answer any questions you might have about this project. Please write or call me or our research coordinator, Ismail A. Abdelmotaleb. Ismail's telephone number is (515) 294-6276; mine is (515) 294-4231.

Thank you for your assistance once again.

Sincerely,

Stephen J. Marley

Stephen J. Marley
Professor

Enclosure: Questionnaire

ID________

1. In this section we ask you to report the total cost of repair and maintenance for <u>each</u> of your tractors separately in 1984 and 1985.

Total repair costs you reported for 1984 $____________

1985 $____________

Tractor Make and Model	Model Year	1984 Repair cost for this tractor	1985 Repair cost for this tractor
1.			
2.			
3.			
4.			
5.			
6.			

2. In this section we ask you to report the total cost of repair and maintenance for <u>each</u> of your combines separately in 1984 and 1985.

Total repair costs you reported for 1984 $____________

1985 $____________

Combine Make and Model	Model Year	1984 Repair cost for this combine	1985 Repair cost for this combine
1.			
2.			

Thank you again for your help. Please return in the envelope provided.

APPENDIX B: SAS COMPUTER PROGRAM TO ESTIMATE REPAIR COSTS

TRACTORS

```
//ISMAIL  JOB I3485,ABDEL
//S1 EXEC SAS
//IN1 DD DISP=SHR,DSN=I.I3485.TRACTOR7
//SYSIN DD *
DATA FIRST;
INFILE IN1;
INPUT MM $ MY YN $ P NU $ YP MRWP MHC HU4 AU4 HU5 AU5 LE RC4 RC5
LH4  LH5 IL $ TAO4 TAO5;
LABEL   MM = MAKE AND MODEL
MY = YEAR MODEL
P = PAYMENT
NY = NEW OR USED
YP = YEAR OF PURCHASED
MRWP = METER HOURS WHEN PURCHASED
MHC = METER HOURS CURRENTLY
HU4 = HOURS USED IN 1984
AU4 = ACRES USED IN 1984
HU5 = HOURS USED IN 1985
AU5 = ACRES USED IN 1985
LE = LIFE EXPECTANCY
RC4 = REPAIR COST 1984
RC5 = REPAIR COST 1985
LH4 = LABOR HOURS 1984
LH5 = LABOR HOURS 1985
IL = LABOR INCLUDING
TAO4 = TOTAL ACRES OPERATED 1984
TAO5 = TOTAL ACRES OPERATED 1985 ;
TAR186=P*1.2*.000631*(MHC*100/12000)**1.6;
MHC11=MHC-HU5;
TAR185=P*1.2*.000631*(MHC11*100/12000)**1.6;
REP185=TAR186-TAR185;
MHC12=MHC-HU5-HU4;
TAR184=P*1.2*.000631*(MHC12*100/12000)**1.6;
REP184=TAR185-TAR184;
TAR286=.100*(MHC*100/12000)**1.5;
MHC21=MHC-HU5;
TAR285=.100*(MHC21*100/12000)**1.5;
REP285P=TAR286-TAR285;
REP285=P*REP285P/100;
N=1985-MY;
REP285I=P*REP285P*(1.05)**N/100;
MHC22=MHC21-HU4;
TAR284=.100*(MHC22*100/12000)**1.5;
REP284P=TAR285-TAR284;
REP284=P*REP284P/100;
N1=1984-MY;
REP284I=P*(1.05)**N1*REP284P/100;
TAR386=.042*(MHC*100/12000)**1.895;
```

```
MHC31=MHC-HU5;
TAR385=.042*(MHC31*100/12000)**1.895;
REP385P=TAR386-TAR385;
REP385=P*REP385P/100;
REP385I=P*REP385P*(1.05)**N/100;
MHC32=MHC31-HU4;
TAR384=.042*(MHC32*100/12000)**1.895;
REP384P=TAR385-TAR384;
REP384=P*REP384P/100;
REP384I=P*REP384P*(1.05)**N1/100;
TAR486=P*(.01*(MHC/1000)**2);
MHC41=MHC-HU5;
TAR485=P*(.01*(MHC41/1000)**2);
REP485=TAR486-TAR485;
REP485I=REP485*(1.05)**N;
MHC42=MHC41-HU4;
TAR484=P*(.01*(MHC42/1000)**2);
REP484=TAR485-TAR484;
REP484I=REP484*(1.05)**N1;
TAR586=1.4*.001*(MHC*100/12000)**2.19;
MHC51=MHC-HU5;
TAR585=1.4*.001*(MHC51*100/12000)**2.19;
REP585P=TAR586-TAR585;
REP585=P*REP585P/100;
N=1985-MY;
REP585I=P*REP585P*(1.05)**N/100;
MHC52=MHC51-HU4;
TAR584=1.4*.001*(MHC52*100/12000)**2.19;
REP584P=TAR585-TAR584;
REP584=P*REP584P/100;
N1=1984-MY;
REP584I=P*(1.05)**N1*REP584P/100;
PROC PRINT;
VAR MM MY RC4 RC5 REP185 REP184 REP285 REP285I REP284 REP284I REP385
REP385I REP384 REP384I    ;
//
```

COMBINES

```
//ISMAIL  JOB I3485,ABDEL
//S1 EXEC SAS
//IN1 DD DISP=SHR,DSN=I.I3485.COMBINE
//SYSIN DD *
DATA FIRST;
INFILE IN1;
INPUT MM $ MY YN $ P NU $ YP MRWP MHC HU4 AU4 HU5 AU5 LE RC4 RC5
LH4  LH5 IL $ TAO4 TAO5;
LABEL   MM = MAKE AND MODEL
MY = YEAR MODEL
P = PAYMENT
NY = NEW OR USED
YP = YEAR OF PURCHASED
MRWP = METER HOURS WHEN PURCHASED
MHC = METER HOURS CURRENTLY
HU4 = HOURS USED IN 1984
AU4 = ACRES USED IN 1984
HU5 = HOURS USED IN 1985
AU5 = ACRES USED IN 1985
LE = LIFE EXPECTANCY
RC4 = REPAIR COST 1984
RC5 = REPAIR COST 1985
LH4 = LABOR HOURS 1984
LH5 = LABOR HOURS 1985
IL = LABOR INCLUDING
TAO4 = TOTAL ACRES OPERATED 1984
TAO5 = TOTAL ACRES OPERATED 1985 ;
TAR186=P*.33*.000251*(MHC*100/2000)**1.8;
MHC11=MHC-HU5;
TAR185=P*.33*.000251*(MHC11*100/2000)**1.8;
REP185=TAR186-TAR185;
MHC12=MHC-HU5-HU4;
TAR184=P*.33*.000251*(MHC12*100/2000)**1.8;
REP184=TAR185-TAR184;
TAR286=.096*(MHC*100/2000)**1.4;
MHC21=MHC-HU5;
TAR285=.096*(MHC21*100/2000)**1.4;
REP285P=TAR286-TAR285;
REP285=P*REP285P/100;
N=1985-MY;
REP285I=P*REP285P*(1.05)**N/100;
MHC22=MHC21-HU4;
TAR284=.096*(MHC22*100/2000)**1.4;
REP284P=TAR285-TAR284;
REP284=P*REP284P/100;
N1=1984-MY;
REP284I=P*(1.05)**N1*REP284P/100;
TAR386=P*(.12*(MHC/1000)**2.1);
```

```
MHC31=MHC-HU5;
TAR385=P*(.12*(MHC31/1000)**2.1);
REP385=TAR386-TAR385;
REP385I=REP385*(1.05)**N;
MHC32=MHC31-HU4;
TAR384=P*(.12*(MHC32/1000)**2.1);
REP384=TAR385-TAR384;
REP384I=REP384*(1.05)**N1;
TAR486=5.64*.001*(MHC*100/2000)**1.86;
MHC41=MHC-HU5;
TAR485=5.64*.001*(MHC41*100/2000)**1.86;
REP485P=TAR486-TAR485;
REP485=P*REP485P/100;
N=1985-MY;
REP485I=P*REP485P*(1.05)**N/100;
MHC42=MHC41-HU4;
TAR484=5.64*.001*(MHC42*100/2000)**1.86;
REP484P=TAR485-TAR484;
REP484=P*REP484P/100;
N1=1984-MY;
REP484I=P*(1.05)**N1*REP484P/100;
PROC PRINT;
VAR MM MY RC4 RC5 REP185 REP184 REP285 REP285I REP284 REP284I REP385
REP385I REP384 REP384I    ;
//
```

APPENDIX C: REPAIR COSTS FOR A SAMPLE OF 50 TRACTORS

TABLE C.1. Repair costs per hour and per acre for a sample of 50 tractors in 1984

Make and model	Year of manu-facture	Reported repair cost in 1984 ($)	Labor hours in 1984 (hrs)	Actual[a] repair cost in 1984 ($)	Hours used in 1984 (hrs)	Acres used in 1984 (acres)	Repair cost in 1984 ($/hr)	Repair cost in 1984 ($/acre)
CASE 2390	1982	546	15	696	258	697	2.70	1.00
INT 966	1972	300	10	400	453	697	0.88	0.57
JD 3020	1964	589	10	689	278	697	2.48	0.99
MAF 48	1979	62	5	112	214	870	0.52	0.13
JD 2750	1984	93	5	143	600	1600	0.24	0.10
WHI 2-7	1976	28	3	58	400	1100	0.14	0.05
CASE	1956	15	3	55	600	.	0.10	.
JD 8650	1983	2500	20	2700	1100	5000	2.45	0.54
JD 3010	1969	900	30	1200	500	5000	2.40	0.24
JD 4020	1971	314	10	414	300	480	1.38	0.86
INT 986	1981	179	30	479	270	360	1.77	1.33
INT 966	1972	1600	10	1700	95	900	17.89	1.89
INT 5088	1984	26	5	76	100	300	0.76	0.25
INT 684	1982	50	5	100	210	.	0.48	.
INT 686	1978	120	5	170	600	400	0.28	0.43
JD 3020	1966	200	10	300	200	200	1.50	1.50
JD 4020	1970	600	5	650	500	650	1.30	1.00
AC 190	1966	987	5	1037	150	440	6.91	2.36
INT 5088	1984	0	0	0	250	700	0.00	0.00
INT 1066	1973	605	5	655	300	700	2.18	0.94
INT 460	1958	126	5	176	20	225	8.80	0.78
INT 1066	1973	4700	30	5000	500	520	10.00	9.62
INT 966	1974	900	10	1000	350	520	2.71	1.83
JD 4230	1974	900	35	1250	500	340	2.50	3.67
JD 4030	1973	80	10	180	400	320	0.45	0.56
INT 1486	1979	1200	10	1300	750	300	1.73	4.33
INT 5088	1983	198	30	498	250	300	1.99	1.66
INT 686	1980	217	30	517	200	300	2.59	1.72
INT 460	1962	263	30	563	200	300	2.82	1.88
INT 784	1984	0	0	0	700	500	0.00	0.00
INT 756	1969	1500	50	2000	400	500	5.00	4.00
JD 4020	1965	350	15	500	450	200	1.11	2.50
AC 7030	1975	3750	100	4750	500	1200	9.50	3.96
CASE 1070	1972	2262	10	2362	800	500	2.95	4.72
JD 8630	1978	675	15	825	420	.	1.96	.
JD 8630	1978	345	15	495	450	.	1.10	.
JD 4630	1978	880	15	1030	410	.	2.51	.
IH 806	1966	295	10	395	152	400	2.60	0.99

JD 4430	1973	500	10	600	150	750	4.00	0.80
JD 4640	1979	500	10	600	300	750	2.00	0.80
INT 1486	1980	1000	20	1200	300	1100	4.00	1.09
JD 4430	1973	800	15	950	400	1735	2.38	0.54
JD 4430	1977	900	15	1050	400	1735	2.63	0.61
INT 1086	1981	400	10	500	400	278	1.25	1.80
INT 884	1979	400	10	500	500	278	1.00	1.80
JD 4460	1979	600	10	700	300	750	2.33	0.93
INT 148	1980	1000	30	1300	300	1100	4.33	1.18
INT 1066	1973	300	10	400	300	700	1.33	0.57
INT 756	1969	400	10	500	100	700	5.00	0.71
INT 5088	1983	100	5	150	250	300	0.60	0.50

[a]Includes labor for repairs at $10.00 /hr.

TABLE C.2. Repair costs per hour and per acre for a sample of 50 tractors in 1985

Make and model	Year of manu- facture	Reported repair cost in 1985 ($)	Labor hours in 1985 (hrs)	Actual[a] repair cost in 1985 ($)	Hours used in 1985 (hrs)	Acres used in 1985 (acres)	Repair cost in 1985 ($/hr)	Repair cost in 1985 ($/acre)
CASE 2390	1982	345	15	495	279	714	1.77	0.69
INT 966	1972	560	10	660	475	714	1.39	0.92
JD 3020	1964	839	10	939	278	714	3.38	1.32
MAF 48	1979	1343	15	1493	205	870	7.28	1.72
JD 2750	1984	165	30	465	650	1700	0.72	0.27
WHI 2-7	1976	144	30	444	400	1100	1.11	0.40
CASE	1956	40	5	90	600	.	0.15	.
JD 8650	1983	2500	20	2700	1100	5000	2.45	0.54
JD 3010	1969	1100	30	1400	500	5000	2.80	0.28
JD 4020	1971	4750	100	5750	300	400	19.17	14.38
INT 986	1981	325	40	725	300	360	2.42	2.01
INT 966	1972	1000	15	1150	100	1100	11.50	1.05
INT 5088	1984	0	0	0	240	650	0.00	0.00
INT 684	1982	167	5	217	300	400	0.72	0.54
INT 686	1978	200	10	300	600	400	0.50	0.75
JD 3020	1966	600	15	750	200	200	3.75	3.75
JD 4020	1970	900	25	1150	600	800	1.92	1.44
AC 190	1966	1525	20	1725	150	440	11.50	3.92
INT 5088	1984	37	5	87	200	700	0.44	0.12
INT 1066	1973	107	5	157	300	700	0.52	0.22
INT 460	1958	299	5	349	200	200	1.75	1.75
INT 1066	1973	500	5	550	500	520	1.10	1.06
INT 966	1974	3300	15	3450	350	520	9.86	6.63
JD 4230	1974	735	11	845	350	600	2.41	1.41
JD 4030	1973	1806	10	1906	350	320	5.45	5.96
INT 1486	1979	900	10	1000	750	300	1.33	3.33
INT 5088	1983	235	10	335	250	300	1.34	1.11
INT 686	1980	312	30	612	200	300	3.06	2.04
INT 460	1962	191	30	491	200	300	2.46	1.64
INT 784	1984	125	20	325	700	500	0.46	0.65
INT 756	1969	2150	50	2650	400	500	6.63	5.30
JD 4020	1965	275	15	425	450	200	0.94	2.13
AC 7030	1975	57	5	107	500	1000	0.21	0.11
CASE 1070	1972	1192	10	1292	800	500	1.62	2.58
JD 8630	1978	372	15	522	430	.	1.21	.
JD 8630	1978	490	15	640	475	.	1.35	.
JD 4630	1978	3265	15	3415	895	.	3.82	.
INT 806	1966	257	10	357	159	400	2.25	0.89

JD 4430	1973	600	10	700	150	750	4.67	0.93
JD 4640	1979	500	10	600	300	750	2.00	0.80
INT 1486	1980	2000	30	2300	300	750	7.67	3.07
JD 4430	1973	800	10	900	400	1000	2.25	0.90
JD 4430	1977	800	15	950	400	1615	2.38	0.59
INT 1086	1981	500	15	650	375	278	1.73	2.34
INT 884	1979	500	10	600	500	278	1.20	2.15
JD 4460	1979	700	13	830	300	750	2.77	1.11
INT 148	1980	2000	50	2500	300	1100	8.33	2.27
INT 1066	1973	200	10	300	300	700	1.00	0.43
INT 756	1969	500	15	650	75	700	8.67	0.93
INT 5088	1983	200	10	300	250	300	1.20	1.00

[a]Includes labor for repairs at $10.00 /hr.

TABLE C.3. 1984 Actual and estimated repair costs for a sample of 50 tractors using 5 ASAE repair equations

Make and model	Year of manu- facture	Reported repair cost in 1984 ($)	Actual repair cost in 1984 ($)	Esti-[a] mated repair cost in 1984 ($)	Dif- ference between actual & est. R.C. ($)	Esti-[b] mated repair cost in 1984 ($)
CASE 2390	1982	546	696	400	-296	449
INT 966	1972	300	400	296	-104	486
JD 3020	1964	589	689	81	-608	186
MAF 48	1979	62	112	701	589	869
JD 2750	1984	93	143	701	558	720
WHI 2-7	1976	28	58	481	423	616
CASE	1956	15	55	42	-13	136
JD 8650	1983	2500	2700	2294	-406	2450
JD 3010	1969	900	1200	325	-875	563
JD 4020	1971	314	414	202	-212	324
INT 986	1981	179	479	253	-226	296
INT 966	1972	1600	1700	80	-1620	127
INT 5088	1984	26	76	20	-56	24
INT 684	1982	50	100	41	-59	51
INT 686	1978	120	170	504	334	597
JD 3020	1966	200	300	88	-211	179
JD 4020	1970	600	650	503	-147	830
AC 190	1966	987	1037	102	-935	202
INT 5088	1984	0	0	124	124	141
INT 1066	1973	605	655	277	-378	423
INT 460	1958	126	176	4	-172	11
INT 1066	1973	4700	5000	563	-4434	839
INT 966	1974	900	1000	276	-724	392
JD 4230	1974	900	1250	800	-450	1123
JD 4030	1973	80	180	415	235	623
INT 1486	1979	1200	1300	1583	283	1767

[a]Equation 1: $TAR = ILP \times RC_1 \times RC_2 \times (L)^{RC_3}$. (See p. 12)

[b]Equation 2: $TAR\ \% = 0.100\ (X)^{1.5}$. (See p. 14)

[c]Equation 3: $TAR\ \% = 0.042\ (TAUh)^{1.895}$. (See p. 16)

[d]Equation 4: $TAR = P\ (RF_1\ (X)^{RF_2})$. (See p. 17)

[e]Equation 5: $TAR\ \% = (1.4 \times (10)^{-3})\ (X)^{2.19}$. (See p. 14)

Difference between actual & est. R.C. ($)	Estimated[c] repair cost in 1984 ($)	Difference between actual & est. R.C. ($)	Estimated[d] repair cost in 1984 ($)	Difference between actual & est. R.C. ($)	Estimated[e] repair cost in 1984 ($)	Difference between actual & est. R.C. ($)
-247	515	-181	229	-467	35	-661
86	853	453	424	24	80	-320
-503	412	-277	218	-471	46	-643
757	1206	1094	563	451	95	-17
577	802	659	354	211	54	-89
558	1338	1280	704	646	148	90
81	361	306	200	145	46	-9
-250	2852	-152	1276	-1423	200	-2500
-637	1423	223	780	-420	176	-1024
-90	757	343	406	-8	88	-326
-183	351	-128	157	-322	25	-454
-1573	255	-1445	131	-1569	27	-1673
-52	13	-63	5	-71	1	-75
-49	46	-54	19	-81	3	-97
427	1201	1031	619	449	125	-45
-121	426	126	230	-70	50	-250
180	2100	1450	1151	501	260	-390
-835	533	-504	295	-742	68	-969
141	105	105	42	42	5	5
-232	811	156	413	-242	81	-574
-165	32	-144	18	-158	4	-172
-4162	1779	-322	930	-4070	193	-4807
-608	833	-167	436	-564	90	-910
-127	2497	1247	1322	72	280	-970
443	1289	1109	670	490	137	-43
467	3700	2400	1929	629	398	-902

TABLE C.3 (Continued)

Make and model	Year of manufacture	Reported repair cost in 1984 ($)	Actual repair cost in 1984 ($)	Estimated[a] repair cost in 1984 ($)	Difference between actual & est. R.C. ($)	Estimated[b] repair cost in 1984 ($)
INT 5088	1983	198	498	159	-339	185
INT 686	1980	217	517	105	-412	129
INT 460	1962	263	563	42	-521	98
INT 784	1984	0	0	820	820	809
INT 756	1969	1500	2000	263	-1737	455
JD 4020	1965	350	500	444	-56	884
AC 7030	1975	3750	4750	618	-4132	816
CASE 1070	1972	2262	2362	956	-1405	1384
JD 8630	1978	675	825	638	-187	780
JD 8630	1978	345	495	518	23	631
JD 4630	1978	880	1030	284	-746	353
IH 806	1966	295	395	133	-262	263
JD 4430	1973	500	600	144	-456	216
JD 4640	1979	500	600	309	-291	406
INT 1486	1980	1000	1200	423	-777	498
JD 4430	1973	800	950	471	-479	692
JD 4430	1977	900	1050	758	-292	937
INT 1086	1981	400	500	545	45	615
INT 884	1979	400	500	417	-83	501
JD 4460	1979	600	700	309	-391	406
INT 148	1980	1000	1300	423	-877	498
INT 1066	1973	300	400	277	-123	423
INT 756	1969	400	500	59	-441	104
INT 5088	1983	100	150	159	9	185

Dif- ference between actual & est. R.C. ($)	Esti-[c] mated repair cost in 1984 ($)	Dif- ference between actual & est. R.C. ($)	Esti-[d] mated repair cost in 1984 ($)	Dif- ference between actual & est. R.C. ($)	Esti-[e] mated repair cost in 1984 ($)	Dif- ference between actual & est. R.C. ($)
-313	154	-344	63	-435	8	-490
-388	149	-368	66	451	10	-507
-465	291	272	167	-396	41	-522
809	1051	1051	483	483	79	79
-1545	1162	-838	639	-1361	145	-1855
384	2791	2291	1662	1122	407	-93
-3934	1895	-2855	1015	-3735	220	-4530
-978	4006	1644	2276	-86	548	-1814
-45	1386	561	692	-133	132	-693
136	1129	634	564	69	108	-387
-677	591	-439	290	-740	54	-976
-132	718	323	402	7	94	-301
-384	447	-153	232	-368	48	-552
-194	445	-155	195	-405	30	-570
-702	698	-502	327	-873	56	-1144
-258	1557	607	827	-123	176	-774
-113	1927	877	1000	-50	204	-846
115	843	343	393	-107	66	-434
1	783	283	378	-122	68	-432
-294	445	-255	195	-505	29	-671
-802	698	-602	327	-973	56	-1244
23	811	411	413	13	81	-319
-396	248	-252	134	-366	29	-471
35	154	4	63	-87	8	-142

TABLE C.4. 1985 Actual and estimated repair costs for a sample of 50 tractors using 5 ASAE repair equations

Make and model	Year of manu-facture	Reported repair cost in 1985 ($)	Actual repair cost in 1985 ($)	Esti-mated repair cost in 1985 ($)[a]	Dif-ference between actual & est. R.C. ($)	Esti-mated repair cost in 1985 ($)[b]
CASE 2390	1982	345	495	511	16	586
INT 966	1972	560	660	344	-316	582
JD 3020	1964	839	939	84	-855	201
MAF 48	1979	1343	1493	732	-761	939
JD 2750	1984	165	465	1087	622	1105
WHI 2-7	1976	144	444	508	64	676
CASE	1965	40	90	44	-46	148
JD 8650	1983	2500	2700	4244	1544	4371
JD 3010	1969	1100	1400	340	-1060	614
JD 4020	1971	4750	5750	209	-5541	350
INT 986	1981	325	725	331	-394	396
INT 966	1972	1000	1150	85	-1065	142
INT 5088	1984	0	0	78	78	92
INT 684	1982	167	217	61	-156	74
INT 686	1978	200	300	554	254	378
JD 3020	1966	600	750	90	-660	192
JD 4020	1970	900	1150	635	-515	1091
AC 190	1966	1525	1725	103	-1622	215
INT 5088	1984	37	87	143	56	161
INT 1066	1973	107	157	292	135	465
INT 460	1958	299	349	4	-345	11
INT 1066	1973	500	550	604	54	935
INT 966	1974	3300	3450	290	-3160	429
JD 4230	1974	735	845	591	-254	864
JD 4030	1973	1806	1906	384	-1522	600
INT 1486	1979	900	1000	1760	760	2027

[a]Equation 1: $TAR = ILP \times RC_1 \times RC_2 \times (L)^{RC_3}$. (See p. 12)

[b]Equation 2: $TAR\ \% = 0.100\ (X)^{1.5}$. (See p. 14)

[c]Equation 3: $TAR\ \% = 0.042\ (TAUh)^{1.895}$. (See p. 16)

[d]Equation 4: $TAR = P\ (RF_1\ (X)^{RF_2})$. (See p. 17)

[e]Equation 5: $TAR\ \% = (1.4 \times (10)^{-3})\ (X)^{2.19}$. (See p. 14)

Difference between actual & est. R.C. ($)	Estimated[c] repair cost in 1985 ($)	Difference between actual & est. R.C. ($)	Estimated[d] repair cost in 1985 ($)	Difference between actual & est. R.C. ($)	Estimated[e] repair cost in 1985 ($)	Difference between actual & est. R.C. ($)
91	749	254	343	-152	56	-439
-78	1095	435	554	-106	108	-552
-738	457	-482	243	-696	52	-887
-554	1378	-115	654	-839	114	-1379
640	1550	1085	727	262	124	-341
232	1523	1079	809	365	173	-271
-58	407	317	228	138	54	-36
1672	7065	4365	3440	740	627	-2073
-786	1600	200	884	-516	202	-1198
-5400	836	-4914	451	-5298	99	-565
-329	522	-203	241	-484	40	-685
-1008	289	-861	149	-1001	30	-1120
92	70	70	28	28	4	4
-143	77	-140	34	-183	5	-212
78	1452	1152	762	462	159	-141
-558	463	-287	250	-500	55	-695
-59	2853	1703	1578	428	362	-788
-1510	570	-1155	316	-1409	73	-1652
74	151	64	63	-24	9	-78
308	925	768	475	318	95	-62
-338	34	-315	19	-330	5	-344
385	2076	1526	1099	549	233	-317
-3021	942	-2508	498	-2952	105	-3345
19	1989	1144	1064	219	229	-616
-1306	1289	-617	676	-1230	141	-1765
1027	4552	3552	2417	1417	515	-485

TABLE C.4 (Continued)

Make and model	Year of manu-facture	Reported repair cost in 1985 ($)	Actual repair cost in 1985 ($)	Esti-mated[a] repair cost in 1985 ($)	Dif-ference between actual & est. R.C. ($)	Esti-mated[b] repair cost in 1985 ($)
INT 5088	1983	235	335	217	-118	251
INT 686	1980	312	612	119	-493	151
INT 460	1962	191	491	43	-448	104
INT 784	1984	125	325	1093	768	1081
INT 756	1969	2150	2650	273	-2377	493
JD 4020	1965	275	425	454	29	947
AC 7030	1975	57	107	654	547	899
CASE 1070	1972	1192	1292	1008	-284	1518
JD 8630	1978	372	522	716	194	905
JD 8630	1978	490	640	603	-37	760
JD 4630	1978	3265	3415	725	-2690	920
INT 806	1966	257	357	141	-216	291
JD 4430	1973	600	700	147	-553	231
JD 4640	1979	500	600	378	-222	505
INT 1486	1980	2000	2300	475	-1825	576
JD 4430	1973	800	900	495	-405	757
JD 4430	1977	800	950	806	-144	1036
INT 1086	1981	500	650	597	-53	688
INT 884	1979	500	600	481	-119	593
JD 4460	1979	700	830	378	-452	505
INT 148	1980	2000	2500	475	-2025	576
INT 1066	1973	200	300	292	-8	465
INT 756	1969	500	650	45	-605	83
INT 5088	1983	200	300	217	-83	251

Difference between actual & est. R.C. ($)	Estimated[c] repair cost in 1985 ($)	Difference between actual & est. R.C. ($)	Estimated[d] repair cost in 1985 ($)	Difference between actual & est. R.C. ($)	Estimated[e] repair cost in 1985 ($)	Difference between actual & est. R.C. ($)
-84	256	-79	110	-225	16	-319
-461	189	-423	86	-526	14	-598
-387	311	-180	179	-312	44	-447
756	1691	1366	816	491	146	-179
-2157	1289	-1361	712	-1938	163	-2487
522	3037	2612	1773	1348	449	24
792	2166	2059	1172	1065	258	151
226	4547	3255	2607	1315	638	-654
383	1709	1187	867	345	170	-352
120	1449	809	737	97	145	-495
-2495	1708	-1707	862	-2553	168	-3247
-66	803	446	450	93	106	-251
-469	486	-214	254	-446	52	-648
-95	632	32	287	-313	46	-554
-1724	871	-1429	417	-1883	73	-2227
-143	1760	860	943	43	204	-696
86	2218	1268	1163	213	242	-708
38	1044	394	500	-150	88	-562
-7	1019	419	504	-96	94	-506
-325	632	-198	287	-543	46	-784
-1924	871	-1629	417	-2083	73	-2427
165	925	625	475	175	95	-205
-567	198	-452	107	-543	24	-626
-49	256	-44	110	-190	16	-284

TABLE C.5. 1984 Actual and estimated repair costs for a sample of 50 tractors using the new repair equation

Make and model	Year of manu-facture	Reported repair cost in 1984 ($)	Actual repair cost in 1984 ($)	Esti-mated repair cost in 1984 ($)[a]	Dif-ference between actual & est. R.C. ($)
CASE 2390	1982	546	696	774	78
INT 966	1972	300	400	672	272
JD 3020	1964	589	689	626	-63
MAF 48	1979	62	112	1045	933
JD 2750	1984	93	143	914	771
WHI 2-7	1976	28	58	797	739
CASE	1956	15	55	1014	959
JD 8650	1983	2500	2700	1524	-1176
JD 3010	1969	900	1200	934	-266
JD 4020	1971	314	414	724	310
INT 986	1981	179	479	594	115
INT 966	1972	1600	1700	502	-1198
INT 5088	1984	26	76	460	384
INT 684	1982	50	100	344	244
INT 686	1978	120	170	853	683
JD 3020	1966	200	300	643	343
JD 4020	1970	600	650	966	316
AC 190	1966	987	1037	739	-298
INT 5088	1984	0	0	558	558
INT 1066	1973	605	655	634	-21
INT 460	1958	126	176	800	624
INT 1066	1973	4700	5000	844	-4156
INT 966	1974	900	1250	703	-547
JD 4230	1974	900	1250	923	-327
JD 4030	1973	80	180	752	572
INT 1486	1979	1200	1300	1127	-173

[a]New equation: Y = .072 TAH + .0096 P + .66 H + 78. (See p. 51)

TABLE C.5 (Continued)

Make and model	Year of manu-facture	Reported repair cost in 1984 ($)	Actual repair cost in 1984 ($)	Esti-mated[a] repair cost in 1984 ($)	Dif-ference between actual & est. R.C. ($)
INT 5088	1983	198	498	584	86
INT 686	1980	217	517	431	-86
INT 460	1962	263	563	918	355
INT 784	1984	0	0	934	934
INT 756	1969	1500	2000	876	-1124
JD 4020	1965	350	500	1246	746
AC 7030	1975	3750	4750	913	-3837
CASE 1070	1972	2262	2552	1356	-1196
JD 8630	1978	675	825	784	-41
JD 8630	1978	345	495	750	255
JD 4630	1978	880	1030	636	-394
IH 806	1966	295	395	803	408
JD 4430	1973	500	600	569	-31
JD 4640	1979	500	600	665	65
INT 1486	1980	1000	1200	693	-507
JD 4430	1973	800	950	816	-134
JD 4430	1977	900	1050	852	-198
INT 1086	1981	400	500	757	257
INT 884	1979	400	500	712	212
JD 4460	1979	600	700	665	-35
INT 148	1980	1000	1300	693	-607
INT 1066	1973	300	400	534	134
INT 756	1969	400	500	592	92
INT 5088	1983	100	150	584	434

TABLE C.6. 1985 Actual and estimated repair costs for a sample of 50 tractors using the new repair equation

Make and model	Year of manu-facture	Reported repair cost in 1985 ($)	Actual repair cost in 1985 ($)	Esti-mated[a] repair cost in 1985 ($)	Dif-ference between actual & est. R.C. ($)
CASE 2390	1982	345	495	808	313
INT 966	1972	560	660	721	61
JD 3020	1964	839	939	646	-293
MAF 48	1979	1343	1493	1054	-439
JD 2750	1984	165	465	994	529
WHI 2-7	1976	144	444	826	382
CASE	1965	40	90	1057	967
JD 8650	1983	2500	2700	1677	-1023
JD 3010	1969	1100	1400	970	-430
JD 4020	1971	4750	5750	746	-5004
INT 986	1981	325	725	635	-90
INT 966	1972	1000	1150	512	-638
INT 5088	1984	0	0	443	443
INT 684	1982	167	217	378	161
INT 686	1978	200	300	896	596
JD 3020	1966	600	750	657	-93
JD 4020	1970	900	1150	1075	-75
AC 190	1966	1525	1725	750	-975
INT 5088	1984	37	87	539	452
INT 1066	1973	107	157	656	499
INT 460	1958	299	349	801	452
INT 1066	1973	500	550	880	330
INT 966	1974	3300	3450	728	-2722
JD 4230	1974	735	845	845	5
JD 4030	1973	1806	1906	744	-1162
INT 1486	1979	900	1000	1182	182

[a]New equation: $Y = .072\ TAH + .0096\ P + .66\ H + 78.$ (See p. 51)

TABLE C.6 (Continued)

Make and model	Year of manufacture	Reported repair cost in 1985 ($)	Actual repair cost in 1985 ($)	Estimated[a] repair cost in 1985 ($)	Difference between actual & est. R.C. ($)
INT 5088	1983	235	335	602	267
INT 686	1980	312	612	445	-167
INT 460	1962	191	491	932	441
INT 784	1984	125	325	984	659
INT 756	1969	2150	2650	905	-1745
JD 4020	1965	275	425	1278	853
AC 7030	1975	57	107	949	842
CASE 1070	1972	1192	1292	1414	122
JD 8630	1978	372	522	821	299
JD 8630	1978	490	640	801	161
JD 4630	1978	3265	3415	1021	-2394
INT 806	1966	257	357	819	462
JD 4430	1973	600	700	580	-120
JD 4640	1979	500	600	687	87
INT 1486	1980	2000	2300	715	-1585
JD 4430	1973	800	900	845	-55
JD 4430	1977	800	950	881	-69
INT 1086	1981	500	650	768	118
INT 884	1979	500	600	748	148
JD 4460	1979	700	830	687	-143
INT 148	1980	2000	2500	715	-1785
INT 1066	1973	200	300	656	356
INT 756	1969	500	650	581	-69
INT 5088	1983	200	300	602	302

APPENDIX D: REPAIR COSTS FOR A SAMPLE OF 50 COMBINES

TABLE D.1. Repair costs per hour and per acre for a sample of 50 combines in 1984

Make and model	Year of manu-facture	Reported repair cost in 1984 ($)	Labor hours in 1984 (hrs)	Actual[a] repair cost in 1984 ($)	Hours used in 1984 (hrs)	Acres used in 1984 (acres)	Repair cost in 1984 ($/hr)	Repair cost in 1984 ($/acre)
MAF 860	1981	1433	55	1983	220	900	9.01	2.20
JD 6620	1982	98	5	148	211	905	0.70	0.16
INT 1440	1981	2000	40	2400	300	850	8.00	2.82
MAF 515	1977	1200	20	1400	180	700	7.78	2.00
JD 7720	1983	25	5	75	260	1100	0.29	0.07
JD 7720	1983	1800	30	2100	270	1500	7.78	1.40
JD 4400	1976	1000	7	1070	200	440	5.35	2.43
JD 720	1979	3000	15	3150	100	600	31.5	5.25
MAF 860	1983	1200	50	1700	300	750	5.67	2.27
JD 6600	1974	1000	40	1400	200	600	7.00	2.33
JD 6620	1981	889	25	1139	250	630	4.53	1.81
INT 1480	1982	1800	100	2800	410	2300	6.83	1.22
JD 7700	1978	2912	20	3112	275	710	11.32	4.38
JD 4420	1982	300	20	500	400	1200	1.25	0.42
JD 6620	1983	400	30	700	247	600	2.83	1.17
MAF 750	1977	890	15	1040	380	650	2.78	1.60
INT 1440	1981	427	20	627	220	600	2.85	1.05
JD 4420	1974	4000	100	5000	100	200	50.00	25.00
JD 6600	1976	10000	150	11500	250	650	46.00	17.69
MAF 510	1977	1200	25	1450	180	443	8.06	3.27
INT 1460	1980	275	3	305	200	600	1.53	0.51
JD 6600	1978	50	10	150	175	440	0.86	0.34
INT 1460	1981	1000	25	1250	480	1400	2.60	0.89
JD 6600	1973	4000	20	4200	180	650	23.33	6.46
JD 150	1969	1000	40	1400	150	400	9.33	3.50
JD 7720	1981	300	30	600	200	1200	3.00	0.50
WHI 890	1980	1000	30	1300	300	1000	4.33	1.30
NI	1979	900	60	1500	250	460	6.00	3.26
JD 6600	1976	1000	10	1100	100	280	11.00	3.93
JD 6600	1975	1000	30	1300	200	700	6.50	1.86
JD 6600	1980	600	50	1100	150	420	7.33	2.62
JD 7800	1983	1500	200	3500	280	700	12.50	5.00
JD 7720	1980	1200	40	1600	280	1600	5.71	1.00
JD 6620	1982	30	5	80	220	650	0.36	0.12
AC	1981	278	12	398	82	328	4.85	1.21
JD 7720	1979	1950	60	2550	206	280	12.38	9.11
NI	1979	1840	19	2030	275	450	7.38	4.51
JD 7720	1980	2700	45	3150	400	1020	7.88	3.09

JD 6600	1974	125	10	225	125	195	1.80	1.15
MAF 750	1978	8000	30	8300	500	350	16.60	23.71
INT 1440	1983	0	0	0	272	682	0.00	0.00
MAF 860	1983	1200	50	1700	300	750	5.67	2.27
JD 6620	1980	310	25	560	310	1000	1.81	0.56
JD 4400	1975	200	12	320	185	295	1.73	1.08
MAF 760	1977	5600	50	6100	200	720	30.5	8.47
JD 6600	1973	3000	30	3300	300	400	11.00	8.25
INT 715	1976	463	10	563	320	700	1.76	0.80
JD 6600	1973	4000	20	4200	180	650	23.33	6.46
JD 6620	1979	4000	40	4400	150	840	29.33	5.24
JD 7720	1980	2700	45	3150	400	1020	7.88	3.09

[a]Includes labor for repairs at $10.00 /hr.

TABLE D.2. Repair costs per hour and per acre for a sample of 50 combines in 1985

Make and model	Year of manu-facture	Reported repair cost in 1985 ($)	Labor hours in 1985 (hrs)	Actual[a] repair cost in 1985 ($)	Hours used in 1985 (hrs)	Acres used in 1985 (acres)	Repair cost in 1985 ($/hr)	Repair cost in 1985 ($/acre)
MAF 860	1981	650	80	1450	216	867	6.71	1.67
JD 6620	1982	110	6	170	211	905	0.81	0.19
INT 1440	1981	2000	40	2400	300	850	8.00	2.82
MAF 515	1977	1800	30	2100	180	700	11.67	3.00
JD 7720	1983	619	60	1219	280	1100	4.35	1.11
JD 7720	1983	2500	30	2800	270	1500	10.37	1.87
JD 4400	1976	1000	15	1150	200	440	5.75	2.61
JD 720	1979	2000	15	2150	150	900	14.33	2.39
MAF 860	1983	1200	50	1700	300	800	5.67	2.13
JD 6600	1974	3000	60	3600	250	800	14.40	4.50
JD 6620	1981	2004	25	2254	250	630	9.02	3.58
INT 1480	1982	2400	120	3600	390	2300	9.23	1.57
JD 7700	1978	4166	20	4366	290	720	15.06	6.06
JD 4420	1982	300	20	500	400	1200	1.25	0.42
JD 6620	1983	500	30	800	240	600	3.33	1.33
MAF 750	1977	4850	50	5350	320	600	16.72	8.92
INT 1440	1981	363	25	613	240	650	2.55	0.94
JD 4420	1974	1000	10	1100	100	200	11.00	5.50
JD 6600	1976	1500	25	1750	300	800	5.83	2.19
MAF 510	1977	650	40	1050	180	443	5.83	2.37
INT 1460	1980	325	3	355	200	600	1.78	0.59
JD 6600	1978	150	25	400	175	440	2.29	0.91
INT 1460	1981	1500	30	1800	480	1400	3.75	1.29
JD 6600	1973	2500	20	2700	180	650	15.00	4.15
JD 150	1969	1000	40	1400	150	400	9.33	3.50
JD 7720	1981	600	30	900	200	1200	4.50	0.75
WHI 890	1980	1000	25	1250	250	800	5.00	1.56
NI	1979	1000	70	1700	225	425	7.56	4.00
JD 6600	1976	1000	10	1100	100	280	11.00	3.93
JD 6600	1975	1000	30	1300	200	700	6.50	1.86
JD 6600	1980	120	20	320	150	420	2.13	0.76
JD 7800	1983	2000	200	4000	250	700	16.00	5.71
JD 7720	1980	2500	40	2900	260	1600	11.15	1.81
JD 6620	1982	1150	10	1250	250	750	5.00	1.67
AC	1981	95	12	215	76	294	2.83	0.73
JD 7720	1979	2200	65	2850	206	780	13.83	3.65
NI	1979	2975	42	3395	275	450	12.34	7.54
JD 7720	1980	3140	70	3840	400	1000	9.60	3.84

JD 6600	1974	150	10	250	150	215	1.67	1.16
MAF 750	1978	1000	30	1300	450	300	2.89	4.33
INT 1440	1983	500	50	1000	272	682	3.67	1.47
MAF 860	1983	1200	50	1700	300	800	5.67	2.13
JD 6620	1982	510	25	760	310	1000	2.45	0.76
JD 4400	1975	250	12	370	170	290	2.18	1.28
MAF 760	1977	3000	45	3450	160	720	21.56	4.79
JD 6600	1973	700	30	1000	200	300	5.00	3.33
INT 715	1976	1974	30	2274	320	650	7.11	3.50
JD 6600	1973	2500	20	2700	180	650	15.00	4.15
JD 6620	1979	3000	40	3400	150	480	22.67	7.08
JD 7720	1980	3140	70	3840	400	1000	9.60	3.84

[a]Includes labor for repairs at $10.00 /hr.

TABLE D.3. 1984 Actual and estimated repair costs for a sample of 50 combines using 4 ASAE repair equations

Make and model	Year of manu-facture	Reported repair cost in 1984 ($)	Actual repair cost in 1984 ($)	Esti-mated[a] repair cost in 1984 ($)	Dif-ference between actual & est. R.C. ($)
MAF 860	1981	1433	1983	2794	811
JD 6620	1982	98	148	1428	1280
INT 1440	1981	2000	2400	1861	-539
MAF 515	1977	1200	1400	964	-436
JD 7720	1983	25	75	1667	1592
JD 7720	1983	1800	2100	815	-1285
JD 4400	1976	1000	1070	1745	675
JD 720	1979	3000	3150	1084	-2066
MAF 860	1983	1200	1700	1615	-85
JD 6600	1974	1000	1400	138	-1262
JD 6620	1981	889	1139	1340	201
INT 1480	1982	1800	2800	7172	4372
JD 7700	1978	2912	3112	2415	-967
JD 4420	1982	300	500	1066	566
JD 6620	1983	400	700	885	185
MAF 750	1977	890	1040	3306	2265
INT 1440	1981	427	627	1190	563
JD 4420	1974	4000	5000	311	-4689
JD 6600	1976	10000	11500	2328	-9172
MAF 510	1977	1200	1450	1570	120
INT 1460	1980	275	305	1316	1011
JD 6600	1978	50	150	788	638
INT 1460	1981	1000	1250	9288	8038
JD 6600	1973	4000	4200	1660	-2540
JD 150	1969	1000	1400	526	-874
JD 7720	1981	300	600	2049	1449

[a]Equation 1: $TAR = ILP \times RC_1 \times RC_2 \times (L)^{RC_3}$. (See p. 12)

[b]Equation 2: $TAR\ \% = 0.096\ (X)^{1.4}$. (See p. 14)

[c]Equation 3: $TAR = P\ (\ RF_1\ \ (X)^{RF_2})$. (See p. 17)

[d]Equation 4: $TAR\ \% = (5.64 \times (10)^{-3})\ (X)^{1.86}$. (See p. 15)

Esti-[b] mated repair cost in 1984 ($)	Dif- ference between actual & est. R.C. ($)	Esti-[c] mated repair cost in 1984 ($)	Dif- ference between actual & est. R.C. ($)	Esti-[d] mated repair cost in 1984 ($)	Dif- ference between actual & est. R.C. ($)
7568	5585	4072	2089	2787	804
4697	4549	1657	1509	1309	1161
4462	2062	2973	573	1891	-509
2280	880	2184	784	1227	-173
5220	5145	1846	1771	1455	1380
2817	717	841	-1259	701	-1399
3720	2650	4657	3587	2388	1318
2068	-1082	2433	-717	1274	-1876
4393	2693	1983	283	1439	-261
364	-1036	371	-1029	204	-1196
3083	1944	2205	1066	1309	170
4989	2189	11661	8861	7032	4232
4376	1264	6142	3030	3027	-85
3869	3369	1172	672	965	465
2943	2243	938	238	766	66
6136	5096	8987	7947	4365	3325
3320	2693	1696	1069	118	-509
974	-4026	737	-4263	449	-4551
5884	-5616	5473	-6027	3106	-8394
3772	2322	3517	2067	1995	545
3144	2839	2220	1915	1414	1109
1887	1737	1626	1476	947	797
16466	15216	18590	17340	9870	8620
3985	-215	5237	1037	2640	-1560
1639	239	1921	521	1007	-393
5156	4556	3154	2554	2066	1466

TABLE D.3 (Continued)

Make and model	Year of manufacture	Reported repair cost in 1984 ($)	Actual repair cost in 1984 ($)	Estimated[a] repair cost in 1984 ($)	Difference between actual & est. R.C. ($)
WHI 890	1980	1000	1300	3577	2277
NI	1979	900	1500	2064	564
JD 6600	1976	1000	1100	572	-528
JD 6600	1975	1000	1300	2085	785
JD 6600	1980	600	1100	992	-108
JD 7800	1983	1500	3500	1679	-1821
JD 7720	1980	1200	1600	2513	913
JD 6620	1982	30	80	67	-13
AC	1981	278	398	259	-139
JD 7720	1979	1950	2550	2652	102
NI	1979	1840	2030	382	-1648
JD 7720	1980	2700	3150	3717	567
JD 6600	1974	125	225	809	584
MAF 750	1978	8000	8300	2429	-5871
INT 1440	1983	0	0	727	727
MAF 860	1983	1200	1700	1615	-85
JD 6620	1980	310	560	2717	2157
JD 4400	1975	200	320	632	312
MAF 760	1977	5600	6100	1590	-4510
JD 6600	1973	3000	3300	3304	4
INT 715	1976	463	563	2245	1682
JD 6600	1973	4000	4200	1660	-2540
JD 6620	1979	4000	4400	1404	-2996
JD 7720	1980	2700	3150	3717	567

Esti-mated repair cost in 1984 ($)[b]	Dif-ference between actual & est. R.C. ($)	Esti-mated repair cost in 1984 ($)[c]	Dif-ference between actual & est. R.C. ($)	Esti-mated repair cost in 1984 ($)[d]	Dif-ference between actual & est. R.C. ($)
8195	6895	6435	5135	3869	2569
4512	3012	4188	2688	2379	879
1506	406	1301	201	758	-342
4930	3630	5607	4307	2970	1670
2501	1401	1660	560	1058	-42
4991	1491	1932	-1568	1477	-2023
6142	4542	4306	2706	2692	1092
330	250	60	-20	58	-22
1136	738	465	67	350	-48
6565	4015	4901	2351	2999	449
788	-1242	808	-1222	444	-1586
9214	6064	6311	3161	3974	824
2280	2055	2076	1851	1187	962
8801	501	3725	-4575	2750	-5550
3115	3115	655	655	608	608
4393	2693	1983	283	1439	-261
7244	6684	3685	3125	2569	2009
1599	1279	1617	1297	892	572
4151	1949	3347	-2753	1995	-4105
6886	3586	11587	8287	5367	2067
5511	4948	5392	4829	3007	2444
3985	-215	5237	1037	2640	-1560
4076	-324	2302	-2098	1550	-2850
9214	6064	6311	3161	3974	824

TABLE D.4. 1985 Actual and estimated repair costs for a sample of 50 combines using 4 ASAE repair equations

Make and model	Year of manu- facture	Reported repair cost in 1985 ($)	Actual repair cost in 1985 ($)	Esti-[a] mated repair cost in 1985 ($)	Dif- ference between actual & est. R.C. ($)
MAF 860	1981	650	1450	3540	2090
JD 6620	1982	110	170	2154	1984
INT 1440	1981	2000	2400	2409	9
MAF 515	1977	1800	2100	1067	-1034
JD 7720	1983	619	1219	2952	1733
JD 7720	1983	2500	2800	1485	-1315
JD 4400	1976	1000	1150	1887	737
JD 720	1979	2000	2150	1716	-434
MAF 860	1983	1200	1700	2435	735
JD 6600	1974	3000	3600	193	-3407
JD 6620	1981	2004	2254	1638	-616
INT 1480	1982	2400	3600	8967	5367
JD 7700	1978	4166	4366	2795	-1571
JD 4420	1982	300	500	2379	1879
JD 6620	1983	500	800	1441	641
MAF 750	1977	4850	5350	3098	-2252
INT 1440	1981	363	613	1725	1112
JD 4420	1974	1000	1100	337	-763
JD 6600	1976	1500	1750	3267	1517
MAF 510	1977	650	1050	1744	694
INT 1460	1980	325	355	1545	1190
JD 6600	1978	150	400	883	483
INT 1460	1981	1500	1800	11359	9559
JD 6600	1973	2500	2700	1773	-927
JD 150	1969	1000	1400	561	-839
JD 7720	1981	600	900	2506	1606

[a]Equation 1: $TAR = ILP \times RC_1 \times RC_2 \times (L)^{RC_3}$. (See p. 12)

[b]Equation 2: $TAR\ \% = 0.096\ (X)^{1.4}$. (See p. 14)

[c]Equation 3: $TAR = P\ (\ RF_1\ \ (X)^{RF_2})$. (See p. 17)

[d]Equation 4: $TAR\ \% = (5.64 \times (10)^{-3})\ (X)^{1.86}$. (See p. 15)

Esti-[b] mated repair cost in 1985 ($)	Dif- ference between actual & est. R.C. ($)	Esti-[c] mated repair cost in 1985 ($)	Dif- ference between actual & est. R.C. ($)	Esti-[d] mated repair cost in 1985 ($)	Dif- ference between actual & est. R.C. ($)
8867	7417	5955	4505	3778	2328
6067	5897	3048	2878	2135	1965
5333	2933	4445	2047	2620	220
2519	419	2637	537	1437	-663
7592	6373	4110	2891	2806	1587
4023	1223	1991	-809	1401	-1399
4062	2912	5445	4295	2727	1577
3347	1197	4129	1979	2127	-23
5675	3975	3647	1947	2348	648
507	-3093	570	-3030	303	-3297
3581	1327	3052	798	1785	-469
7173	3573	16936	13336	9419	5819
5075	709	7727	3361	3704	-662
6200	5700	3578	3078	2387	1887
3904	3104	1930	1130	1359	559
5725	375	9209	3859	4332	-1018
4386	3773	2869	2256	1837	1224
1065	-35	864	-236	514	-586
8016	6266	8548	6798	4629	2879
4175	3125	4268	3218	2345	1295
3578	3223	3001	2646	1765	1410
2097	1697	1996	1596	1124	724
19124	17324	25731	23931	12866	11066
4325	1625	6022	3322	2977	277
1777	377	2205	805	1134	-266
5989	5089	4365	3465	2693	1793

TABLE D.4 (Continued)

Make and model	Year of manufacture	Reported repair cost in 1985 ($)	Actual repair cost in 1985 ($)	Estimated[a] repair cost in 1985 ($)	Difference between actual & est. R.C. ($)
WHI 890	1980	1000	1250	3622	2372
NI	1979	1000	1700	2131	431
JD 6600	1976	1000	1100	611	-489
JD 6600	1975	1000	1300	2279	979
JD 6600	1980	120	320	1141	821
JD 7800	1983	2000	4000	2338	-1662
JD 7720	1980	2500	2900	2910	10
JD 6620	1982	1150	1250	197	-1053
AC	1981	95	215	385	170
JD 7720	1979	2200	2850	3112	262
NI	1979	2975	3395	438	-2957
JD 7720	1980	3140	3840	5112	1272
JD 6600	1974	150	250	1056	806
MAF 750	1978	1000	1300	4129	2829
INT 1440	1983	500	1000	1805	805
MAF 860	1983	1200	1700	2435	735
JD 6620	1982	510	760	3922	3162
JD 4400	1975	250	370	638	268
MAF 760	1977	3000	3450	1445	-2005
JD 6600	1973	700	1000	2349	1349
INT 715	1976	1974	2274	2655	381
JD 6600	1973	2500	2700	1773	-927
JD 6620	1979	3000	3400	1668	-1732
JD 7720	1980	3140	3840	5112	1272

Estimated repair cost in 1985 ($)[b]	Difference between actual & est. R.C. ($)	Estimated repair cost in 1985 ($)[c]	Difference between actual & est. R.C. ($)	Estimated repair cost in 1985 ($)[d]	Difference between actual & est. R.C. ($)
7906	6656	7354	6104	4174	2924
4567	2867	4778	3078	2605	905
1635	535	1499	399	855	-245
5412	4112	6653	5353	3432	2132
2816	2496	2111	1791	1290	970
5862	1862	3316	-684	2230	-1770
6691	3791	5685	2785	3328	428
656	-594	246	-1004	190	-1060
1189	974	553	338	398	183
7468	4618	6411	3561	3740	890
887	-2508	1025	-2370	540	-2855
11356	7516	10252	6412	5876	2036
2996	2746	2937	2687	1637	1387
11542	10242	8276	6976	5130	3830
5361	4361	2260	1260	1679	679
5675	3975	3647	1947	2348	648
9151	8391	6391	5631	4000	3240
1617	1247	1774	1404	951	581
3717	267	3351	-99	1923	-1527
4978	3978	8864	7864	4027	3027
6295	4021	7131	4857	3783	1509
4325	1625	6022	3322	6977	4277
4665	1265	3062	-338	1958	-1442
11356	7516	10252	6412	5876	2036

TABLE D.5. 1984 Actual and estimated repair costs for a sample of 50 combines using the new repair equation

Make and model	Year of manufacture	Reported repair cost in 1984 ($)	Actual repair cost in 1984 ($)	Estimated repair cost in 1984 ($)[a]	Difference between actual & est. R.C. ($)
MAF 860	1981	1433	1983	2112	129
JD 6620	1982	98	148	1619	1471
INT 1440	1981	2000	2400	1119	-1281
MAF 515	1977	1200	1400	1352	-48
JD 7720	1983	25	75	1618	1543
JD 7720	1983	1800	2100	1438	-662
JD 4400	1976	1000	1070	1439	369
JD 720	1979	3000	3150	816	-2334
MAF 860	1983	1200	1700	781	-919
JD 6600	1974	1000	1400	1668	268
JD 6620	1981	889	1139	627	-512
INT 1480	1982	1800	2800	3630	830
JD 7700	1978	2912	3112	1361	-1751
JD 4420	1982	300	500	1575	1075
JD 6620	1983	400	700	500	-200
MAF 750	1977	890	1040	1753	713
INT 1440	1981	427	627	795	168
JD 4420	1974	4000	5000	1264	-3736
JD 6600	1976	10000	11500	2015	-9485
MAF 510	1977	1200	1450	1345	-105
INT 1460	1980	275	305	834	529
JD 6600	1978	50	150	800	650
INT 1460	1981	1000	1250	2608	1358
JD 6600	1973	4000	4200	2344	-1856
JD 150	1969	1000	1400	2706	1306
JD 7720	1981	300	600	1835	1235

[a]New equation: Y = 241.70 N + .016 P + 2.27 H + 1.07 A - 1894.9. (See p. 69)

TABLE D.5 (Continued)

Make and model	Year of manu- facture	Reported repair cost in 1984 ($)	Actual repair cost in 1984 ($)	Esti-[a] mated repair cost in 1984 ($)	Dif- ference between actual & est. R.C. ($)
WHI 890	1980	1000	1300	1932	632
NI	1979	900	1500	1007	-493
JD 6600	1976	1000	1100	1040	-60
JD 6600	1975	1000	1300	2118	818
JD 6600	1980	600	1100	606	-494
JD 7800	1983	1500	3500	998	-2502
JD 7720	1980	1200	1600	2372	772
JD 6620	1982	30	80	43	-37
AC	1981	278	398	222	-176
JD 7720	1979	1950	2550	1346	-1204
NI	1979	1840	2030	516	-1514
JD 7720	1980	2700	3150	2086	-1064
JD 6600	1974	125	225	1521	1296
MAF 750	1978	8000	8300	2016	-6284
INT 1440	1983	0	0	960	960
MAF 860	1983	1200	1700	781	-919
JD 6620	1980	310	560	1708	1148
JD 4400	1975	200	320	1254	934
MAF 760	1977	5600	6100	1738	-4362
JD 6600	1973	3000	3300	2301	-999
INT 715	1976	463	563	2022	1459
JD 6600	1973	4000	4200	2344	-1856
JD 6620	1979	4000	4400	1819	-2581
JD 7720	1980	2700	3150	2086	-1064

TABLE D.6. 1985 Actual and estimated repair costs for a sample of 50 combines using the new repair equation

Make and model	Year of manufacture	Reported repair cost in 1985 ($)	Actual repair cost in 1985 ($)	Estimated[a] repair cost in 1985 ($)	Difference between actual & est. R.C. ($)
MAF 860	1981	650	1450	2310	860
JD 6620	1982	110	170	1860	1690
INT 1440	1981	2000	2400	1361	-1039
MAF 515	1977	1800	2100	1593	-507
JD 7720	1983	619	1219	1905	686
JD 7720	1983	2500	2800	1679	-1121
JD 4400	1976	1000	1150	1681	531
JD 720	1979	2000	2150	1493	-657
MAF 860	1983	1200	1700	1076	-624
JD 6600	1974	3000	3600	2237	-1363
JD 6620	1981	2004	2254	869	-1385
INT 1480	1982	2400	3600	3826	226
JD 7700	1978	4166	4366	1647	-2719
JD 4420	1982	300	500	1816	1316
JD 6620	1983	500	800	726	-74
MAF 750	1977	4850	5350	1805	-3545
INT 1440	1981	363	613	1136	523
JD 4420	1974	1000	1100	1506	406
JD 6600	1976	1500	1750	2531	781
MAF 510	1977	650	1050	1587	537
INT 1460	1980	325	355	1075	720
JD 6600	1978	150	400	1042	642
INT 1460	1981	1500	1800	2849	1049
JD 6600	1973	2500	2700	2586	-114
JD 150	1969	1000	1400	2948	1548
JD 7720	1981	600	900	2077	1177

[a]New equation: $Y = 241.70\ N + .016\ P + 2.27\ H + 1.07\ A - 1894.9$. (See p. 69)

TABLE D.6 (Continued)

Make and model	Year of manu- facture	Reported repair cost in 1985 ($)	Actual repair cost in 1985 ($)	Esti-[a] mated repair cost in 1985 ($)	Dif- ference between actual & est. R.C. ($)
WHI 890	1980	1000	1250	1846	596
NI	1979	1000	1700	1155	-545
JD 6600	1976	1000	1100	1282	182
JD 6600	1975	1000	1300	2359	1059
JD 6600	1980	120	320	848	528
JD 7800	1983	2000	4000	1171	-2829
JD 7720	1980	2500	2900	2568	-332
JD 6620	1982	1150	1250	374	-876
AC	1981	95	215	413	198
JD 7720	1979	2200	2850	2124	-726
NI	1979	2975	3395	758	-2637
JD 7720	1980	3140	3840	2306	-1534
JD 6600	1974	150	250	1814	1591
MAF 750	1978	1000	1300	2090	790
INT 1440	1983	500	1000	1202	202
MAF 860	1983	1200	1700	1076	-624
JD 6620	1982	510	760	1950	1190
JD 4400	1975	250	370	1457	1087
MAF 760	1977	3000	3450	1889	-1561
JD 6600	1973	700	1000	2209	1209
INT 715	1976	1974	2274	2211	-63
JD 6600	1973	2500	2700	2586	-114
JD 6620	1979	3000	3400	1675	-1725
JD 7720	1980	3140	3840	2306	-1534

APPENDIX E: STATISTICAL ANALYSIS

TABLE E.1. Simple descriptive statistics for testing the validity of the ASAE repair cost formula for tractors: $TAR = ILP \times RC_1 \times RC_2 \times (L)^{RC3}$

Item	1984	1985
N[a]	98	106
SUM	34413.6	38933.2
MEAN	351.16	367.29
VARIANCE	863015	992712
STD DEV[b]	928.986	996.35
CV[c]	264.55	271.27
T:MEAN=0[d]	3.742	3.795
PROB>|T|[e]	0.00031	0.00025

[a]The number of observations on which the calculation are based.
[b]The standard deviation.
[c]The coefficient of variation.
[d]The student's t value for testing the hypothesis that the population mean is 0.
[e]The probability of a greater absolute value for this t value.

TABLE E.2. Simple descriptive statistics for testing the validity of the ASAE repair cost formula for tractors: TAR = 0.100 $(X)^{1.5}$

Item	1984	1985
N[a]	98	106
SUM	37595.8	43930.4
MEAN	383.63	414.437
VARIANCE	875547	968192
STD DEV[b]	935.707	983.967
CV[c]	243.908	237.422
T:MEAN=0[d]	4.0587	4.3364
PROB>|T|[e]	0.0001	0.0001

[a]The number of observations on which the calculation are based.
[b]The standard deviation.
[c]The coefficient of variation.
[d]The student's t value for testing the hypothesis that the population mean is 0.
[e]The probability of a greater absolute value for this t value.

TABLE E.3. Simple descriptive statistics for testing the validity of the ASAE repair cost formula for tractors: TAR = 0.042 $(TAUH)^{1.895}$

Item	1984	1985
N[a]	98	106
SUM	9755.78	2478.35
MEAN	99.5487	23.3806
VARIANCE	955041	1458635
STD DEV[b]	977.262	1207.74
CV[c]	981.692	5165.56
T:MEAN=0[d]	1.00841	0.199313
PROB>|T|[e]	0.31576	0.84240

[a]The number of observations on which the calculation are based.
[b]The standard deviation.
[c]The coefficient of variation.
[d]The student's t value for testing the hypothesis that the population mean is 0.
[e]The probability of a greater absolute value for this t value.

TABLE E.4. Simple descriptive statistics for testing the validity of the ASAE repair cost formula for tractors: TAR = P $(RF_1 (X)^{RF2})$

Item	1984	1985
N[a]	99	106
SUM	41501.6	45447.3
MEAN	419.208	428.748
VARIANCE	820900	887996
STD DEV[b]	906.036	942.335
CV[c]	216.13	219.787
T:MEAN=0[d]	4.603	4.6843
PROB>|T|[e]	0.0001	0.0001

[a]The number of observations on which the calculation are based.
[b]The standard deviation.
[c]The coefficient of variation.
[d]The student's t value for testing the hypothesis that the population mean is 0.
[e]The probability of a greater absolute value for this t value.

TABLE E.5. Simple descriptive statistics for testing the validity of the ASAE repair cost formula for tractors: $Y = (1.4 \times 10^{-3}) X^{2.19}$

Item	1984	1985
N[a]	98	106
SUM	64898.6	81486.8
MEAN	662.23	768.74
VARIANCE	890315	870743
STD DEV[b]	943.565	933.136
CV[c]	142.483	121.385
T:MEAN=0[d]	6.94785	8.4818
PROB>|T|[e]	0.0001	0.0001

[a]The number of observations on which the calculation are based.
[b]The standard deviation.
[c]The coefficient of variation.
[d]The student's t value for testing the hypothesis that the population mean is 0.
[e]The probability of a greater absolute value for this t value.

TABLE E.6. Regression analysis for fitting the best model of tractor repair costs

	FORWARD SELECTION PROCEDURE FOR DEPENDENT VARIABLE REPAIR COST				COST
		R SQUARE[a] = 0.0698	C(P)[b] = 4.2863		
	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	1	10670886.9589	10670886.9589	13.44	0.0003
ERROR	179	142108816.0355	793904.0002		
TOTAL	180	152779702.9945			
	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	494.6526				
H[c]	0.78918	0.21525	10670886.9589	13.44	0.0003
	BACKWARD ELIMINATION PROCEDURE FOR DEPENDENT VARIABLE REPAIR COST				
		R SQUARE[a] = 0.0975	C(P)[b] = 2.8851		
	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	3	14904899.2930	4968299.7643	6.38	0.0005
ERROR	177	137874803.7014	778953.6932		
TOTAL	180	152779702.9945			
	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	77.5635				
H[c]	0.65916	0.22854	6479899.4948	8.32	0.0044
TAH[d]	0.07237	0.03186	4017728.0289	5.16	0.0243
P[e]	0.00955	0.00556	2294654.4157	2.95	0.0878

STEPWISE REGRESSION PROCEDURE FOR DEPENDENT VARIABLE REPAIR COST

R SQUARE[a] = 0.0975 C(P)[b] = 2.8851

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	3	14904899.2930	4968299.7643	6.38	0.0005
ERROR	177	137874803.7014	778953.6932		
TOTAL	180	152779702.9945			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	77.5635				
H[c]	0.65916	0.22854	6479899.49487	8.32	0.0044
TAH[d]	0.07237	0.03186	4017728.0289	5.16	0.0243
P[e]	0.00955	0.00556	2294654.4157	2.95	0.0878

[a]The square of multiple correlation coefficient.
[b]Statistic proposed by Mallows.
[c]Annual hours of use.
[d]Total accumulated hours of use.
[e]Purchase price.

TABLE E.7. Simple descriptive statistics for testing the validity of the new repair cost equation for tractors: $Y = 0.072\,X + 0.0096\,P + 0.66\,H + 78$

Item	1984	1985
N[a]	98	106
SUM	595.29	8146.47
MEAN	6.01	76.85
VARIANCE	847809	856701
STD DEV[b]	920.77	925.58
CV[c]	15312.9	1204.35
T:MEAN=0[d]	0.0649	0.8549
PROB>|T|[e]	0.94832	0.3945

[a]The number of observations on which the calculation are based.
[b]The standard deviation.
[c]The coefficient of variation.
[d]The student's t value for testing the hypothesis that the population mean is 0.
[e]The probability of a greater absolute value for this t value.

TABLE E.8. Simple descriptive statistics for testing the validity of the ASAE repair cost formula for combines: TAR = ILP x RC_1 x RC_2 x $(L)^{RC3}$

Item	1984	1985
N[a]	124	122
SUM	-101502	-56298.2
MEAN	-818.564	-461.461
VARIANCE	4701216	5089113
STD DEV[b]	2168.23	2255.91
CV[c]	-264.882	-488.862
T:MEAN=0[d]	-4.2039	-2.2594
PROB>|T|[e]	0.0001	0.02564

[a]The number of observations on which the calculation are based.
[b]The standard deviation.
[c]The coefficient of variation.
[d]The student's t value for testing the hypothesis that the population mean is 0.
[e]The probability of a greater absolute value for this t value.

TABLE E.9. Simple descriptive statistics for testing the validity of the ASAE repair cost formula for combines: TAR % = 0.096 $(X)^{1.4}$

Item	1984	1985
N[a]	122	124
SUM	-272358	-318366
MEAN	-2232.44	-2567.46
VARIANCE	10437230	9820756
STD DEV[b]	3230.67	3133.81
CV[c]	-144.715	-122.059
T:MEAN=0[d]	-7.6325	-9.1231
PROB>|T|[e]	0.0001	0.0001

[a]The number of observations on which the calculation are based.
[b]The standard deviation.
[c]The coefficient of variation.
[d]The student's t value for testing the hypothesis that the population mean is 0.
[e]The probability of a greater absolute value for this t value.

TABLE E.10. Simple descriptive statistics for testing the validity of the ASAE repair cost formula for combines: TAR = $P(RF_1 (X)^{RF2})$

Item	1984	1985
N[a]	122	124
SUM	-193270	-293542
MEAN	-1584.18	-2367.28
VARIANCE	10448188	11150841
STD DEV[b]	3232.37	3339.29
CV[c]	-204.04	-141.06
T:MEAN=0[d]	-5.41332	-7.8941
PROB>|T|[e]	0.0001	0.0001

[a]The number of observations on which the calculation are based.
[b]The standard deviation.
[c]The coefficient of variation.
[d]The student's t value for testing the hypothesis that the population mean is 0.
[e]The probability of a greater absolute value for this t value.

TABLE E.11. Simple descriptive statistics for testing the validity of the ASAE repair cost formula for combines: $Y = (5.64 \times 10^{-3})\ X^{1.86}$

Item	1984	1985
N[a]	122	124
SUM	-30081.5	-72668.1
MEAN	-246.57	-586.033
VARIANCE	4670807	4312674
STD DEV[b]	2161.2	2076.7
CV[c]	-876.509	-354.366
T:MEAN=0[d]	-1.26015	-3.142
PROB>|T|[e]	0.2100	0.0021

[a]The number of observations on which the calculation are based.
[b]The standard deviation.
[c]The coefficient of variation.
[d]The student's t value for testing the hypothesis that the population mean is 0.
[e]The probability of a greater absolute value for this t value.

TABLE E.12. Regression analysis for fitting the best model of combine repair costs

	FORWARD SELECTION PROCEDURE FOR DEPENDENT VARIABLE REPAIR COST				COST
		R SQUARE[a] = 0.1958	C(P)[b] = 5.4731		
	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	3	190452380.7163	63484126.9054	19.48	0.0001
ERROR	240	782050135.3492	3258542.2306		
TOTAL	243	972502516.0655			
	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-1462.9023				
N[c]	231.2997	46.8787	79327187.1197	24.34	0.0001
P[d]	0.0162	0.0062	22628681.9991	6.94	.0090
A[e]	1.2542	0.2147	111128535.6051	34.10	0.0001

	BACKWARD ELIMINATION PROCEDURE FOR DEPENDENT VARIABLE REPAIR COST				
		R SQUARE[a] = 0.2054	C(P)[b] = 4.5984		
	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	4	199762218.6536	49940554.6634	14.45	0.0001
ERROR	239	772740297.4119	3233223.0017		
TOTAL	243	972502516.0655			
	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-1894.8608				
N[c]	241.6991	47.0966	85154007.9396	26.34	0.0001
P[d]	0.0159	0.0061	21716911.9763	6.72	0.0101
A[e]	1.0721	0.2393	64886879.7209	20.07	0.0001
H[f]	2.2741	1.3401	9309837.9372	2.88	0.0910

STEPWISE REGRESSION PROCEDURE FOR DEPENDENT VARIABLE REPAIR COST

R SQUARE[a] = 0.2054 C(P)[b] = 4.5984

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	4	199762218.6536	49940554.6634	14.45	0.0001
ERROR	239	772740297.4119	3233223.0017		
TOTAL	243	972502516.0655			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	-1894.8608				
N[c]	241.6991	47.0966	85154007.9396	26.34	0.0001
P[d]	0.0159	0.0061	21716911.9763	6.72	0.0101
A[e]	1.0721	0.2393	64886879.7209	20.07	0.0001
H[f]	2.2741	1.3401	9309837.9372	2.88	0.0910

[a]The square of the multiple correlation coefficient.
[b]Statistic proposed by Mallows.
[c]Age of the combine.
[d]Purchase price.
[e]Annual harvested acres.
[f]Annual hours of use.

TABLE E.13. Simple descriptive statistics for testing the validity of the new repair cost equation for combines: Y = 241.70 N + .016 P + 2.27 H + 1.07 A - 1894.9

Item	1984	1985
N[a]	122	124
SUM	-15590.25	-32605.80
MEAN	-127.789	-262.95
VARIANCE	2611824	3567546
STD DEV[b]	1616.11	1888.79
CV[c]	-1264.67	-718.31
T:MEAN=0[d]	-0.9488	-1.653
PROB>|T|[e]	0.3442	0.1005

[a]The number of observations on which the calculation are based.
[b]The standard deviation.
[c]The coefficient of variation.
[d]The student's t value for testing the hypothesis that the population mean is 0.
[e]The probability of a greater absolute value for this t value.